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NEW TECHNOLOGY FOR OIL/WATER EMULSION TREATMENT: PHASES I AND II

S. VENKATESH, Ph.D
C. WATSON
C.D. WOLBACH, Ph.D.
L.R. WATERLAND, Ph.D

ARCADIS GERAGHTY & MILLER
555 CLYDE AVE.
P.O. BOX 7044
MOUNTAIN VIEW CA 94039

BATTELLE
COLUMBUS OPERATIONS
505 KING AVE.
COLUMBUS OH 43201

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AIR FORCE RESEARCH LABORATORY
MATERIALS & MANUFACTURING DIRECTORATE
AIRBASE & ENVIRONMENTAL TECHNOLOGY DIVISION
TYNDALL AFB FL 32403-5323

NOTICES

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

DENNIS O'SULLIVAN, 1LT, USAF, BSC
Program Manager

ALLAN M. WEINER, Lt Col, USAF
Chief, Environmental Technology
Development Branch

ANDREW D. POULIS
Scientific & Technical
Information Program Manager

NEIL J. LAMB, Col, USAF, BSC
Chief, Airbase & Environmental
Technology Division

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13. ABSTRACT *(Maximum 200 words)*

Air Force bases (AFBs) have numerous discharge streams from industrial processes that contain high levels of oils and greases. These streams are nominally treated with oil/water separators (OWSs). Large numbers of OWSs at AFBs are targeted for replacement as they reach the end of their performance lives. The AFBs need reliable, high performance replacements to meet increasingly stringent environmental regulations on oily water discharges. The ACARDIS Geraghty & Miller/Battelle Team (ABT) was contracted by the Armstrong Laboratory/Environics Directorate to identify and evaluate candidate technologies as replacements for existing DWSs. This report covers the Phase II Field Evaluation activities of the two-phase project.

Under the Phase I activities it was determined that high technology/high cost solutions faced significant hurdles to implementation, and that existing units were probably not performing because of maintenance problems. Phase II was carried out to determine if this assumption was true, and if low cost solutions would perform adequately to meet regulatory standards. Several simple technologies and one high technology solution were operated in parallel on a aircraft wash rack discharge stream to compare performance. Technologies studied included a simple gravity separator, a gravity separator with coalescing media, a gravity separator with coalescing media and biological treatment, a clay filter system, and a high-technology membrane filtration system were used. The results of the tests, along with economic analysis, are presented.

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EXECUTIVE SUMMARY

ARCADIS Geraghty & Miller, Inc. (formerly Acurex Environmental Corporation) and Battelle Columbus Operations conducted a two-phase study and test program of oil/water (O/W) separation systems for United States Air Force wastewater treatment operations. Phase I researched and documented the current status of O/W separation at selected Air Force Bases using interviews with personnel, site team visual assessments, and quantitative analytical review of influent and effluent wastewater streams from selected O/W separators. The site assessment team concluded that a variety of factors, including outdated separation technology, poor maintenance of separators, and incomplete knowledge of the wastewater stream to be treated, were causing inefficient separation to occur. Nine of the 20 separators sampled had effluent concentrations greater than 100 mg/L, a standard regulatory limit for oil and grease (O&G) discharged to public treatment plants.

Phase II efforts applied commercial off-the-shelf O/W separation technologies to the aircraft wash rack (ACWR) discharge at Dover Air Force Base (AFB), in Delaware. The study also treated wastewater from a jet engine test cell (JETC), a vehicle wash rack (VWR), and a lagoon. Technologies for the separation of mechanically dispersed oil in water emulsions and chemically emulsified oils were evaluated. Simple gravity separators (SGS), and SGS with coalescing media, were chosen as treatment technologies for the treatment of mechanically dispersed oils. Organoclay filtration, membrane separation, and chemical demulsification technologies were chosen to treat chemically emulsified oils. SGS with coalescing media, further augmented with biotreatment, was chosen as an integrated system to handle both mechanically and chemically emulsified oils.

The discharge from the ACWR facility at Dover AFB can be characterized as a low-O&G-concentration, high-flow-rate waste stream. The average O&G concentration, primarily mechanically emulsified O&G, was less than 100 mg/L during a typical aircraft washing cycle. The SGS, and the SGS with coalescers, both treated the waste streams with almost equal efficiency, and reduced the O&G concentrations to below 50

mg/L, in general. However, it was observed that, during the course of the test program, the test units containing the coalescers produced an effluent with a consistent O&G quality, and visibly lower solids contents, than the SGS-only unit, which showed a wider range of effluent O&G concentrations and visibly higher solids contents under similar test conditions. The SGS, and the SGS with coalescers, are relatively easy to operate and require minimal maintenance, in the form of periodic sludge removal and cleaning of the coalescers. The SGS, and the SGS with coalescers, are also referred to as primary treatment systems, as they are typically the first step in the treatment of O&G removed from wastewater streams.

Organoclay filtration, membrane separation, and chemical demulsification treatment methods all produced effluent streams with O&G concentrations of less than 10 mg/L. The organoclay filtration system was the least complex to operate, whereas the chemical demulsification process was the most complex. The membrane separation system was a complex unit that required significant operator attention during startup and shutdown, but was generally easy to operate. Such systems as these are also referred to as secondary treatment or post-treatment systems, or polishing systems, because they frequently follow the primary treatment systems. The extent and type of secondary treatment system used will depend upon the level of O&G removal required. Secondary treatment systems, such as those described above, provide additional capabilities, including the removal of most hydrocarbons and metals from the wastewater stream, resulting in a high-quality discharge wastewater possibly suitable for recycling. Requirements for secondary treatment systems will be dictated by the discharge needs of the individual facility and by the economics.

Biotreatment of the wastewater stream for O&G removal was tested by introducing the oil-consuming bacteria, with nutrients, into two independent SGS units with coalescers. Test data showed biotreatment to be somewhat better at removing O&G than either SGS or SGS with coalescers. It is believed that, for biotreatment to perform at optimum efficiency, both longer residence times and a longer test period are required. (The field tests lasted a total of 5 weeks.) Furthermore, the superior performance of biotreatment over gravity-based separation could not be fully measured

because of the low influent O&G concentration that was started with. Despite these constraints, however, biotreatment results showed consistently lower O&G concentrations compared to both the SGS and the SGS with coalescers. Another important observation made during the test program, and one which may affect the operations and maintenance requirements for SGS and coalescing-media-based systems, is that the coalescers in the biotreatment unit remained relatively clean over the course of the test program, and were eventually the easiest to clean at the end of the test program. A more detailed evaluation study needs to be conducted on biotreatment for O&G removal from wastewater streams. However, biotreatment appears to be a promising and cost-effective emerging technology for O/W treatment.

Key findings and recommendations resulting from this test program are as follows:

- Older conventional technologies such as SGS systems, which are presently the mainstays in O/W separation in the Air Force (AF) have limited capabilities. Within the AF, the performance of these, and other, more sophisticated O/W separation systems, is typically below standards because of poor to nonexistent maintenance, the use of undersized equipment, and the use of old equipment.
- The field-test phase of the project showed that cost-effective options such as retrofitting existing SGS systems with coalescers and biotreatment may achieve the same results as replacing these systems with new systems. Replacing an existing system with a new one, without a clear understanding of the characteristics of the wastewater stream, however, is clearly not a solution to existing O/W problems.
- The Phase I base survey indicated that personnel in charge of operating the O/W separators lacked critical data concerning the operation of the separators, such as flow rates, detailed O&G concentration profiles, detergent levels, and the nature of the O&G dispersions. These data are important not only in the routine operation of the existing separators, but also in the design and procurement of new, replacement separators. Not knowing

- A number of secondary treatment systems exist that can provide a very high-quality effluent discharge, with an O&G concentration of typically less than 10 mg/L. Secondary treatment systems are relatively expensive in terms of capital investment, and operations and maintenance, and must be carefully evaluated before being implemented.
- Maintenance and monitoring are important for the proper operation of any separator. In addition, the capabilities and limits of the separator must be well understood by the operator to ensure that the separator is operated properly. The operator must possess a basic understanding of the science and engineering involved in separation processes in order to recognize the operating and performance envelopes of the separator. Basic scientific principles of separation, and the engineering aspects of a variety of separators, are included in the appendices to this report in order to assist the operator in understanding separators, and to assist the base engineer in selecting a new separator or an alternative solution to the O/W problem at his or her base.

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LIST OF ACRONYMS

ACWR	Aircraft wash rack
AF	United States Air Force
AFB	United States Air Force Base
AGE	Aerospace ground equipment
AL/EQS	Armstrong Laboratories/Environics Directorate
ASH	Air sparged hydrocyclone
COD	Chemical oxygen demand
COTS	Commercial off-the-shelf
DAF	Dissolved air flotation
EPA	United States Environmental Protection Agency
IDIQ	Indefinite deliverable, indefinite quantity
JETC	Jet engine test cell
MBAS	Methylene blue active substances
NOV	Notice of violation
O/W	Oil/water
O&G	Oil and grease
O&M	Operation and maintenance
POC	Point of contact
POTW	Publicly owned treatment works
QFS	Quantity of filterable solids
RE	Removal efficiency
SGS	Simple gravity separator
TOC	Total organic carbon
TSS	Total suspended solids
VWR	Vehicle wash rack

SECTION I
INTRODUCTION

A. PROGRAM OBJECTIVE

The primary objective of this study was to identify separation technologies that would be applicable to treating Air Force base (AFB) industrial wastewater streams. A wide variety of activities at AFBs generate oily wastewater, but general similarities exist in the types of oil, brands of detergent used, degrees of mixing, and flowrates found at various sources. Clear knowledge of wastewater stream characteristics and target treatment standards allows specific separators or types of separators to be recommended for a variety of operations that generate similar wastewater streams.

There are many commercial off-the-shelf (COTS) technologies available for O/W separation. Thus, one of the objectives of this study was to classify the technologies according to cost, applicability, advantages, and drawbacks. In this way, AFB personnel can review the study reports to find technologies that may work in a given situation and to avoid technologies that have been found to be difficult to apply or ineffective. Specific vendors or brandnames of technologies are included for reference only and are not intended as endorsement of the vendors or the brandname technologies.

B. BACKGROUND

U.S. Air Force (AF) operations generate wastewater streams with varying degrees of oily contamination. Oil/water (O/W) emulsions can lower the effectiveness of many industrial oil separation processes and result in effluent streams that are out of compliance with local discharge limits. Local municipalities are increasing efforts to enforce discharge limits which could lead to AF installations receiving Notices of Violations (NOVs) and fines for discharging unauthorized concentrations of oil and grease (O&G) to publicly owned treatment works (POTWs). The source of high O&G concentrations in discharge wastewater has been linked to inadequate performance of existing O/W separators. Reliably low O&G concentrations in wastewater discharge streams are needed at AFBs; current operations dictate that this be accomplished by

P2/phase, first by pollution prevention/source reduction techniques, then by installing and maintaining reliable O/W separators.

The AF has documented the need for assessing or developing advanced technologies for removing O/W emulsions and suspended solids from contaminated wastewater (ESOH 912). To address this need, Air Force Research Laboratory APRL/MLQ initiated research, development, testing, and evaluation of treatment technologies for O/W emulsions and suspended solids.

This research and evaluation program proceeded in two phases, Phase I and Phase II. This Final Report reviews the efforts and results of both phases of the study of AF-applicable O/W separation technologies. It contains all of the study-generated information necessary for the reader to make informed decisions regarding the selection of O/W separators, bearing in mind that separation technologies have varying capital and maintenance costs, as well as varying degrees of effectiveness and required treatment times. Specifically, this Final Report contains recommendations for reliable and cost-effective treatment technologies, and guidelines for selecting a technology appropriate to a particular wastewater stream. The Phase I and Phase II reports provide more detailed descriptions of the current state of oily wastewater treatment at AFBs, and the raw data from testing conducted on these technologies at Dover AFB.

C. PROGRAM APPROACH

The program was conducted in two phases. Phase I was initiated in February 1996 and continued through February 1997 with the completion of the *Draft Scientific and Technical Report for New Technology for Oil/Water Emulsion Treatment — Phase I* and the *Draft Technical Literature and Technology Review for Physiochemical Processes for Oil/Water Emulsion Treatment for IDIQ Contract Task 3, New Technology for Oil/Water Emulsion Treatment — Phase I.* The Phase I efforts included a detailed review of the literature available on COTS O/W separation technologies and a survey of the operations of more than 50 O/W separators located in five AFBs. The technical literature and technology review discusses the theory behind O/W separation and the operations common to O/W separation. The base survey revealed the critical

problems experienced with O/W separators operating in AFBs and identified potential solutions to these problems. As the next phase of the program, selected COTS technologies were targeted for field evaluation.

Phase II began in March 1997 and concluded in November 1997 with the report *Draft Scientific and Technical Report for New Technology for Oil/Water Emulsion Treatment — Phase II Field Testing of Technologies.* Efforts for this phase included field testing of selected separation technologies on actual AFB wastewater streams. The selection represented a range of technologies with potential for installation or retrofit at AF facilities generating oily wastewater streams. Based on the survey of AFBs in Phase I, Dover AFB was selected as the site for the technology evaluation field tests. The field test program was conducted by ARCADIS Geraghty & Miller, Inc. (formerly Acurex Environmental Corporation) at Dover AFB between May 27 and July 17, 1997.

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SECTION II

CONCLUSIONS AND RECOMMENDATIONS

This section presents the key findings and recommendations which AFB personnel will find valuable in selecting an appropriate O/W treatment system or upgrading an existing system. While one separation technology may perform very well on one stream, it may not be appropriate for treating another. Caution should always be used when selecting equipment that is intended to last and perform for many years. If two or more technologies are found with similar treatment capabilities, a lifecycle cost analysis should be performed which specifically includes capital costs, maintenance costs and disposal costs as appropriate. In this way, cost-effective separation technologies can be selected for treating wastewater discharge streams.

A. CONCLUSIONS

Based on the results of the test program, we have drawn the following conclusions:

- **Older technologies, such as simple gravity separators (SGS), work best when treating streams with high concentrations of mechanically dispersed oil and grease.** These separation technologies, with or without coalescing plates, are commonly found at AFBs. This study showed that at influent O&G levels of approximately 1000 mg/L or greater, the separation efficiency for these units averages about 75%. At O&G levels at and below 100 mg/L the separation efficiency for these units is much lower, about 25% (see Section IV, Tables IV-2 and IV-3). Although such separators can marginally meet present discharge requirements, if stricter regulatory limits become requirements, SGS technology alone will not be sufficient. Chemical demulsification of oils due to the presence of surfactants requires other treatment technologies.
- **Enhanced separation and improved removal efficiencies through the addition of coalescing media was observed.** The field-test program studies indicate that, in general, the addition of coalescing media to an

otherwise simple gravity separator improves O&G removal. Test data on SGS with coalescing media indicated that this combination had better removal efficiency than SGS alone, and also that it was better at solids removal and had a more consistent effluent quality in terms of O&G concentrations. The study data also showed that both removal efficiency and O&M will be functions of the type of coalescing media used. For example, smaller spacing between parallel-plate media increases the coalescence rate and, thereby, the removal efficiency; but, at the same time, can also increase the potential of the plates clogging.

- **In the treatment of chemically demulsified oils, the field-test data showed that such oils can be removed by using a number of technologies.** Chemical demulsification, membrane separation, and organoclay filtration systems were all tested, and exhibited a high level of efficiency at removing emulsified oils. Each of these three systems has both merits and deficiencies, in terms of cost and O&M. Selection of the appropriate system for a given application will depend upon the requirements of the individual facility. Another system tested was biotreatment. Although not as effective as the other three in removing emulsified oils, biotreatment demonstrated the potential of providing cost-effective solutions to O/W treatment problems. Biotreatment has shown promise for easy application to existing facilities at relatively lower costs. In addition, it has the potential to treat both mechanically and chemically dispersed oils. Biotreatment is still considered an emerging technology in this field, however, and requires further evaluation.
- **Separation technology will be specific to a given wastewater stream.** No one separator type will be applicable to all wastewater streams generated in an AFB. Phase II testing showed that the more conventional technologies, such as SGS with coalescers and bioaugmentation, may work well on streams with mechanically dispersed O&G. Chemically demulsified oils, on the other hand, will require other technologies.

- **In existing separator maintenance and performance, the main factors leading to poor removal of oil from wastewater streams in AF facilities are the use of outdated separator technologies, the undersizing of equipment, and the improper maintenance of the existing separators.** Few separators listed in the Base Survey (Appendix B) had coalescing elements to enhance separation; and many were below grade, with no leak-detection capabilities. State-of-the-art technologies, purchased to replace antiquated O/W separators, were not functional primarily because they were improperly installed. The Base Survey showed that the methods used for evaulating separator efficiency are inadequate. Data on typical wastewater stream flowrates, pH, influent temperature, and recommended residence times for adequate separation had either not been collected or were unavailable. In general, AFB personnel lacked the factual data necessary to base decisions regarding the performance of existing O/W separators or the projected performance of possible replacements to these separators.
- **Maintenance and responsible monitoring are invaluable.** Even a well-designed separator for a particular wastewater stream may have difficulty handling the same stream when different cleansers or different pressure washing techniques change the nature of the stream's O/W emulsion. O/W separation is not an exact science. Maintaining the efficient operation of an O/W separation technology requires that operators responsibly check the effluent stream for visible oil in the discharge, regularly inspect for clogs or leaks, test the effluent to check separation efficiency, dredge settled sludge and solids, regularly skim to remove surface oil, and routinely clean coalescers. All these activities are maintenance efforts important to effective O/W separator operation.

B. RECOMMENDATIONS

The following recommendations are made for addressing existing O&G problems, for purchasing new O/W treatment systems, and for general O&M:

- **Select the simplest O/W separation technology adequate for meeting discharge needs.** Capital costs, installation costs, maintenance costs, and frequency of maintenance all increase with increasing complication of technology. All advanced technologies purchased for O/W separation by various AF entities were inoperational at the time of the base survey. If discharge requirements dictate the use of a more sophisticated technology, it may be cost effective to contract the maintenance of the process. Do not select a delicate technology for a rough environment.
- **Newer technologies will require more maintenance efforts.** The degree of maintenance required for a selected O/W separator technology must be assessed before purchase of the equipment. In general, the more advanced the technology, the more extensive the operations and maintenance efforts will be for proper operation. If high efficiency separation is required, it is often practical to hire a contractor to maintain the advanced technology separators. For example, a contractor could be used to maintain nutrient and bacteria levels for bioaugmentation, remove spent organoclay and replace with new clay, or routinely test the effluent of the wastewater treatment process to ensure that the units are functioning properly.
- **Operators must understand the basic principles of O/W dispersions and emulsions.** A working knowledge of the science of O/W separation may be obtained through studying Appendices A, C, and D of this report.
- **Operators must be aware of the flow characteristics of the wastewater stream to be treated.** If the stream operates at steady flow and comes from a similar process at all times, then selecting a treatment technology based on the average O&G concentrations and flowrates may be acceptable. However, most AF operations are cyclic or intermittent. Although flow to a separator might average 40,000 gallons per week, that flow might come in four 10,000-gallon cycles, with each cycle lasting six hours and having a variable flowrate of from 5 to 100 gallons per minute (gpm). A separator designed to handle 4 gpm (40,000 gallons evenly distributed over one week) would not be

sufficient to handle the actual wastewater stream with peak flowrates of 100 gpm. Similar considerations hold for oil concentrations. In order to control surges and spikes in both flowrate and oil concentration, it is often practical to combine several wastewater streams for treatment, and/or employ a large holding tank followed by a separator to process a steady flow. These strategies have been successfully employed at Luke and Edwards AFBs, respectively.

- **Designers of new O/W technologies should clearly understand the needs of the operators purchasing these technologies.** In turn, the operators must be fully aware of their needs from an engineering viewpoint. Before an O/W separation system is designed or implemented, it is important that the concerned parties understand the nature of the stream in terms of the O&G concentration, the O&G specific gravity, the pH, the temperature, the solids concentration, the detergent concentration, the quantity of chemically emulsified oils, the flow rates, and the applicable regulatory requirements.

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SECTION III

PHASE I

A. OBJECTIVE AND APPROACH

The objectives of Phase I were to investigate and document the current status of oily wastewater separation and discharge at a representative number of AFBs across the United States, and to assemble a technical report and technology review of currently available and applicable O/W separation technologies. An approach was developed and applied to the characterization of O/W separator effluent streams at AFBs known or suspected to contain elevated O&G and particulate matter. Wastewater discharge standards were reviewed to determine the status of past or possible future AFB violations of these standards.

When assessing a wastewater stream for O/W separator compatibility, it is necessary to first understand the type of oil-in-water suspension present in the wastewater stream. Three kinds of suspensions exist: free oil, mechanically dispersed or emulsified oil, and chemically emulsified oil. Free oil and mechanically dispersed oil are sometimes grouped together, as both can be separated from the water matrix by physical means. Mechanically dispersed oil ranges from free oil that separates quickly and easily to mechanically emulsified oil with droplets so fine the emulsion is nearly stable. High shear rinsing with a pressure washer often yields a mechanically emulsified oil; detergents used with high shear rinsing results in an emulsion that is both mechanically and chemically emulsified. Emulsions are described and discussed in greater detail in Appendix A.

In general, the smaller the oil droplets dispersed in the water matrix, the more difficult it will be to separate the two phases. Free oil is typically removed by gravity separation methods. Chemically emulsified oils, and some finely dispersed mechanical emulsions, are removed by special means employing chemical demulsifying agents, adsorption, or special filtration techniques.

B. AFB SURVEY REPORT

A preliminary list of 21 AF installations was assembled by conducting phone surveys to collect information on existing or anticipated problems with O/W separator effluent streams. The information collected from these surveys was summarized and returned to the applicable base personnel for review. Criteria were developed for selecting bases to visit for in-depth data collection and effluent stream sampling and analysis. These criteria gave preference to selecting bases that:

- Share common processes while using a variety of types and conditions of O/W separator types and a variety of operating conditions for a given type
- Conduct operations of large volume and scale
- Currently employ a number of different separator technologies
- Have ongoing improvement plans
- Suspect an O/W emulsion problem
- Desire to participate in the project by hosting a survey visit
- Represent the major AF commands

The following bases were selected for base visits:

- Cannon AFB (Air Combat Command)
- Dover AFB (Air Mobility Command)
- Luke AFB (Air Education and Training Command)
- Mountain Home AFB (Air Combat Command)
- Wright-Patterson AFB (Air Force Material Command)

Base points-of-contact (POCs) were contacted at each base to determine the specific O/W separators to include in the base survey sampling scope. Most frequently suggested were separators treating effluent from aircraft washracks (ACWR), vehicle washracks (VWR), jet engine test cells (JETC), and aerospace ground equipment (AGE) washracks. Most separators selected for the survey were old, gravity-type concrete basins or steel chambers, subdivided with single or multiple baffles.

Three to five separators per surveyed base were targeted for testing. At each base, influent and effluent samples were collected from the selected O/W separators. Composite samples were sent to Lancaster Laboratories in Lancaster, PA, for O&G and

total suspended solids (TSS) tests by EPA method 413.2 and EPA 160.2 respectively. The discharge standards set by local and state regulatory agencies vary, but most require the O&G content of the treated effluent to be below 100 mg/L. Nine of the 20 separators sampled had effluent concentrations greater than 100 mg/L and six had concentrations higher than 200 mg/L.

Few separators had coalescing elements to enhance separation, and many were below grade with no leak-detection capabilities. In general, the separators appeared to be poorly maintained, with excessive oil/sludge build-up and/or clogged piping. The separators were often inappropriately sized for proper treatment of their influent wastewater stream. State-of-the-art technologies, purchased to replace antiquated O/W separators, were not functional during any of the site visits due, in all cases, to improper installation.

The main factors leading to poor removal of oil from wastewater streams in AF facilities are the use of outdated separator technologies, undersizing of equipment, and improper maintenance of the existing separators. The base survey showed that the methods used for evaluating separator efficiency, specified maintenance frequencies, and criteria for selecting replacement technologies to be inadequate. Data on typical wastewater stream flowrates, pH, influent temperature, and recommended residence times for adequate separation either had not been collected or were unavailable. In general, AFB personnel interviewed lacked factual data on which to base decisions regarding the performance of existing O/W separators or the projected performance of their possible replacements.

Phase I surveys demonstrated that engine test cells, AGE washracks and ACWRs generate wastewater which may exceed permissible discharge limits. Most of these streams are treated by some kind of O/W separator, however the effectiveness of individual separators sampled varied from negligible, for ACWR and the engine test cell O/W separators, to barely adequate for the AGE washrack O/W separator. The principal material of the Phase I report is included as Appendix B.

C. TECHNOLOGY REVIEW

A detailed technical literature/technology review was conducted to identify COTS and emerging technologies for O/W and suspended solids separation. These technologies were assessed against six criteria important to AF installations: (1) general applicability, (2) separation efficiency, (3) operational and design requirements, (4) maintenance requirements and reliability, (5) commercial availability, and (6) cost. The results are documented in Appendix C. Technical literature from several periodicals, trade journals, and electronic databases, combined with information from experts in academia as well as equipment manufacturers and vendors, provided the basis of the report. The review of technologies covered solid/liquid and liquid/liquid separation.

Appendix C outlines the theory and practice of O/W separation as well as the general applicability, separation efficiency, design requirements, maintenance requirements, commercial availability, and cost of individual technologies. This effort was designed to assist AF installations in developing a short-list of technology options for the treatment of oily wastewater and to enable users to be able to perform their own evaluation of O/W separators.

The technologies reviewed were: simple gravity separation (SGS), coalescers to augment SGS, dissolved air flotation (DAF), hydrocyclone, centrifugation, bioaugmentation, organoclay absorption, membrane separation, chemical addition, and electro-acoustic separation. SGS, SGS with coalescers, centrifuges, hydrocyclones, and DAF rely on Stokes Law to effect separation. By relying on the difference in density between oil and water, these technologies perform best when treating lightly dispersed free oil without detergents in the wastewater stream. They are generally considered to be effective primary separation systems for use when effluent O&G concentrations do not need to be below 100 mg/L.

Organoclays, membranes, and chemical addition are all advanced technologies appropriate for treating finely dispersed O&G or streams with emulsifying detergents. Organoclays absorb the oil while membranes rely on ultrafiltration to separate oil and water phases. Chemical demulsification, as well as emerging technologies such as

electro-acoustic separation and air-sparged hydrocyclone (ASH), can be used on stabilized emulsions with varying degrees of success. ASH has proven itself particularly effective on chemically stabilized emulsions. The relatively new technology of bioaugmentation of a coalescing separator with oleophilic bacteria to digest the suspended oil may work on all three kinds of oil in water suspensions with the added advantage of not merely separating the oil, but eliminating it.

Technologies were evaluated on the basis of application flexibility, cost, and O&M requirements. Tabular summaries assessing the technologies against these criteria were prepared to assist AFB personnel requiring a new O/W separator in forming a short-list of possibly applicable technologies. Although this report can assist in the selection of an O/W separator, there is sufficient variety in vendor technology and wastewater stream characteristics that the report should be used only as a guide.

At the end of Phase I, it was unclear whether the surveyed separators were inefficient because they were poorly maintained, undersized, and overwhelmed by the volume and flowrate of the influent stream, or simply too old and outdated to meet stricter discharge requirements. In Phase II, new COTS and emerging technologies were selected for testing at Dover AFB on actual wastewater streams from the ACWR, JETC, VWR and lagoon at the base. These tests were designed to clarify the issues raised in Phase I.

SECTION IV
PHASE II

A. OBJECTIVE AND APPROACH

The objective of the field test program performed in Phase II was to evaluate the performance of new O/W separation technologies on a wide range of wastewater streams at a representative AFB. Dover AFB was selected as the test site. The criteria for the technology evaluation were to include:

- Separation effectiveness
- Operating and maintenance (O&M) requirements
- Overall cost of installation and O&M

Oily wastewater from AF facilities can contain both free, or mechanically dispersed oil, and chemically emulsified oil. Depending on the amounts of free and chemically emulsified oil, both primary treatment, such as gravity separation, to remove free oil, and secondary treatment, such as adsorption, to remove emulsified oil, may be required.

Seven O/W separation technologies were selected for testing in the field test program. These technologies represented well-established as well as emerging primary and secondary treatment methods. The seven technologies were:

Primary Treatment Technologies

- Simple gravity separation (SGS)
- SGS augmented by parallel-plate slant-rib coalescers
- SGS augmented by vertical-tube coalescers
- Biotreatment

Secondary Treatment Technologies

- Polymeric membrane ultrafiltration
- Organoclay filtration
- Chemical demulsification
- Biotreatment

Biotreatment is classified as both a primary and secondary treatment technology. Primary because it is capable of treating high concentration oil streams and performs best when added in the beginning of the treatment process; secondary as it requires more maintenance efforts than SGS and like chemical demulsification requires regular materials addition to the treatment system. The seven technologies, and the criteria for selecting them, are described in detail in Section B.

B. DESCRIPTION OF OIL/WATER SEPARATION TECHNOLOGIES EVALUATED IN THE FIELD TEST PROGRAM

A comprehensive review of commercial off-the-shelf technologies and emerging technologies for oil/water (O/W) separation with potential for application to Air Force (AF) maintenance facilities was presented in a report[IV-1] prepared under Phase I of this project. Based on the conclusions from that document, specific O/W separation technologies were selected for the field test program.

As noted in Section A, O/W separation technologies, in general, can be categorized into two classes:

I. Primary treatment methods. These include the class of separators that are capable of removing mechanically dispersed oil (free oil) and solids. Gravitational force is used as the separation principle. Gravity separation is typically augmented by the application of coalescing media, centrifugal forces, or air flotation. Devices that do not use any augmentation are commonly known as simple gravity separators.

II. Secondary treatment methods. These are processes or methods that are capable of removing chemically emulsified oil. Secondary treatment is also commonly referred to as "post treatment" or "polishing."

1. Technology Selection Criteria

The Phase I base survey[IV-2] (see Appendix B) of more than 75 O/W separators at five AFBs concluded that the primary causes of separator failure were poor maintenance, outdated separation equipment, and undersizing of equipment. Therefore, the focus of this program was on:

- Evaluation of emerging technologies

- Evaluation of operation and maintenance requirements
- Proper sizing of equipment

Both primary and secondary treatment technologies were selected for evaluation. Primary treatment technologies included a baseline SGS and SGSs augmented with coalescing media. Two types of coalescing media were evaluated. One was the more conventional slant-rib parallel-plate type coalescing media. The other incorporated a newer design vertical-tube type coalescing media. Both types of coalescing media were made of plastic oleophilic material.

Secondary or post-treatment technologies were also evaluated. The secondary treatment technologies included:

- Polymeric membrane ultrafiltration
- Organoclay filtration
- Biological treatment
- Chemical treatment

2. Description of Separation Technologies Tested

Table IV-1 gives a summary of the technologies selected for testing. The following subsections describe each of these separation technologies.

a. Baseline Simple Gravity Separator

A Great Lakes Environmental, Inc., model SRC-M2 separator was converted into the baseline separator. The SRC-M2 consists of a simple gravity separation tank augmented by slant-rib coalescing media. For this test program, the coalescing media were removed and the tank was used as the baseline (control) simple gravity separator. Figure IV-1 is a photograph of the baseline separator while the coalescing media were still in place. The tank had an operating capacity of approximately 75 gallons. A vendor description brochure for the separator is included in Appendix F-1.

b. Slant-Rib Parallel-Plate O/W Separator

The PressureClear™ (PC) O/W separator was provided by TurnKey, Solutions, Inc. The PC is a complete primary treatment device with capabilities for convenient sludge and oil removal. Free oil removal is augmented in its

main chamber with the help of slant-rib parallel-plate oleophilic coalescing media. The PC system also came with a post-treatment filter system for the removal of any suspended solids. Figure IV-2 is a photograph of the PC system used in this test program.

TABLE IV-1. SUMMARY OF THE O/W SEPARATION TECHNOLOGIES TESTED.

Technology Type	Test Unit Capacity	Trade Name	Vendor
Primary Treatment			
Baseline simple gravity separator (SGS)	2 gpm	SRC-M2	Great Lakes Environmental, Inc. 315 S. Stewart Ave. Addison, IL 60101 T: (630) 543 9444
SGS augmented by slant-rib parallel-plate coalescers	5 gpm	PressureClear	TurnKey Solutions, Inc. 103 Godwin Ave. Midland Park, NJ 07432 T: (201) 848-7676
SGS augmented by vertical-tube coalescers	5 gpm	VTC-5	AFL Industries 3661-F W. Blue Heron Blvd. Riviera Beach, FL 33404 T: (407) 844-5200
Secondary Treatment			
Polymeric-membrane ultrafiltration	300 gpd	Koch Ultrafiltration Membrane	TurnKey Solutions, Inc. 103 Godwin Ave. Midland Park, NJ 07432 T: (201) 848-7676
Organoclay Filtration	5 lb oil per 1 lb of clay	ClaySorb	TurnKey Solutions, Inc. 103 Godwin Ave. Midland Park, NJ 07432 T: (201) 848-7676
Biotreatment	(a)	None	BioSolutions, Inc. 5 Stratton Dr. Westborough, MA 01581 T: (800) 240-2400
Chemical treatment. Demulsification followed by flocculation	(a)	WEB 3 WEB 40A	Midwest Custom Chemical, Inc. 5700 Prospect Dr., P.O. Box 8727 Newburgh, IN 47629 T: (812) 858-3147

[a]Other primary treatment processes were augmented with the biotreatment and chemical treatment approaches.

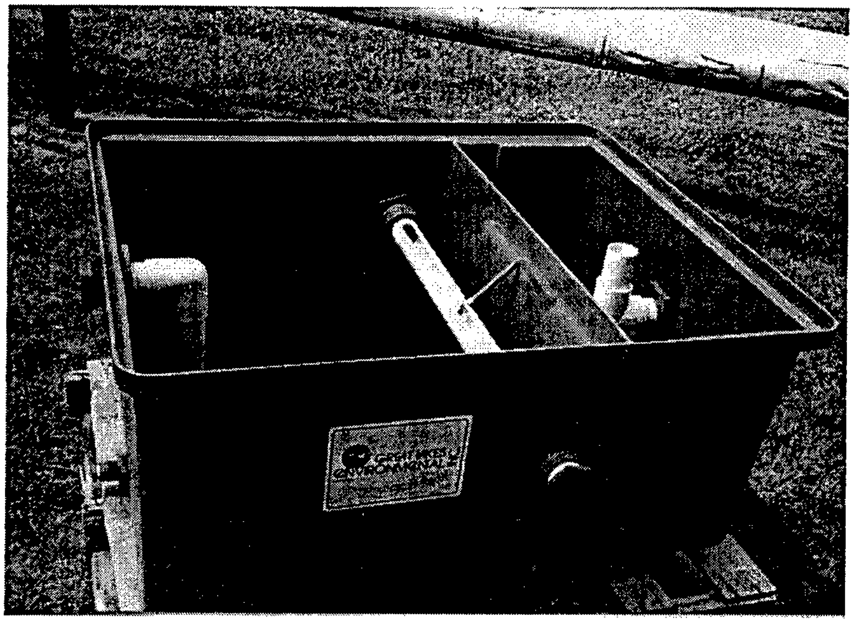

Figure IV-1. Photograph of the Baseline Simple Gravity Separator (the Coalescing Media Seen in the Photograph Were Removed for the Test Program).

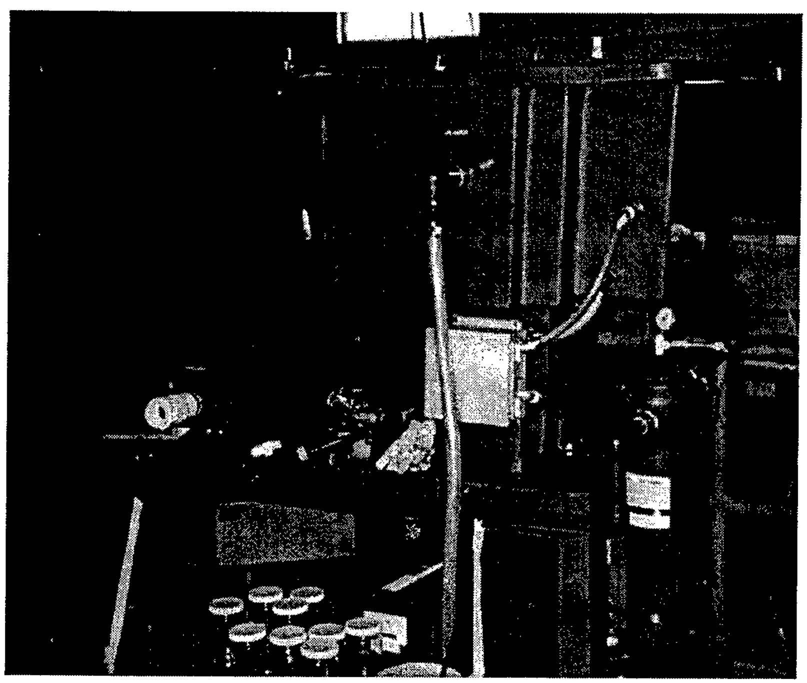

Figure IV-2. Photograph of the PressureClear O/W Separator.

The operating volume of the PC O/W separator was approximately 80 gallons, with a corresponding rated processing rate of 5 gpm. The main chamber containing the coalescing media had a hoppered bottom where separated sludge is collected for removal. Treated water flowed through a set of baffles before reaching the final outlet reservoir. This outlet reservoir had a capacity of approximately 3 gallons, and contained a level-switch-activated electrical pump that periodically discharged the treated water. The discharge water flowed through a filter that removed any remaining suspended material. The vendor description and schematics of the PC separator are included in Appendix F-2.

c. Vertical Tube Coalescer

A gravity separator containing vertical tube coalescers rated for a processing capacity of 5 gpm was also tested. This separator, called the VTC-5™ by its vendor, contained a large main chamber and a smaller second chamber. The main chamber housed the coalescer tubes and a rotary pipe oil-skimmer. Each coalescer tube was composed of a polymer mesh formed into a cylinder, the mesh comprising the cylinder wall. Tubes were arranged in a honeycomb matrix with the tubes oriented vertically. Inlet wastewater enters from one side of the main chamber and flows horizontally (perpendicular to the coalescer tubes axes) to the opposite chamber side. Separated oil rises through the center of the tubes, while suspended particulates settle downward. Oil-free water passes out the discharge side of the chamber into the second chamber. This separator had an approximate operating volume of 45 gallons in the main chamber. Figure IV-3 is a photograph of the VTC-5 unit in operation during the test program. Schematic diagrams and vendor-supplied descriptions of the VTC-5 are given in Appendix F-3. The unit was approximately 3 feet in diameter and 2.5 feet high.

d. Polymeric Membrane Ultrafiltration

Polymeric membrane systems are used mainly as secondary separation devices. While they can be used as primary treatment systems to remove the free oil and solids, they would be cost-prohibitive in such applications. The membrane unit selected for this test was a Koch ultrafiltration polymeric membrane

system with a rated capacity of 300 gpd for a wastewater stream containing high levels (>1,000 mg/L) of O&G and solids.

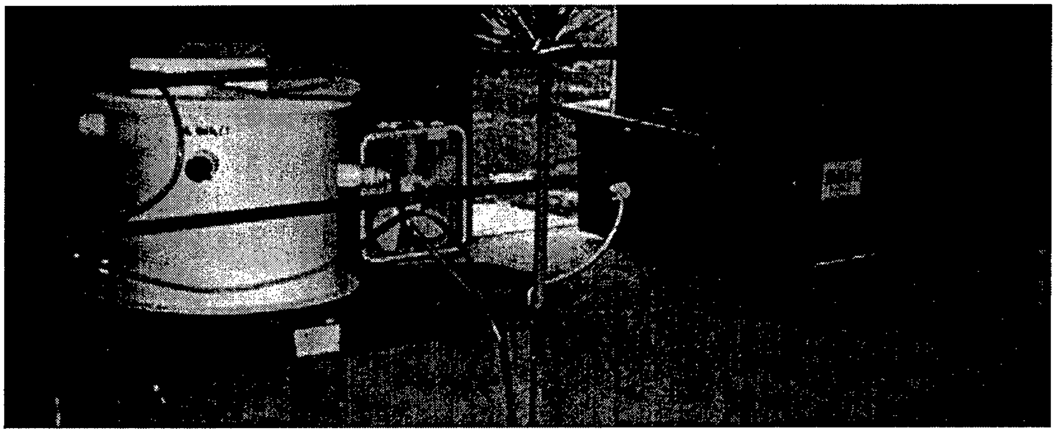

Figure IV-3. Photograph of the VTC-5 Unit.

Figure IV-4 is a photograph of the membrane filtration system tested. Detailed schematics of the membrane system are included in Appendix F-4. The influent wastewater passes through a filter bag (100 µm mesh size) to remove suspended solids, and then flows into a 50-gallon process tank. A recirculating process pump circulates the wastewater through a hollow-fiber membrane pack. Filtered water passes through the membrane. The O&G and the solids are retained by the membrane and accumulate in the process tank. Processing continues with fresh wastewater makeup until the build-up of O&G and solids in the process tank dictates their removal via a cleaning cycle. The unit's operating manual suggests a treatment guideline of 10 times the process tank capacity between cleaning cycles.

e. Organoclay Filtration

The organoclay filtration system tested, also provided by TurnKey Solutions, Inc., used an organically modified clay, termed ClaySorb™, as the filtration medium. A mixture of bentonite and anthracite coal treated with a quaternary amine, the ClaySorb product is designed to remove mechanically dispersed oil, chemically emulsified oil, large molecular weight chlorinated hydrocarbons, and heavy metals.

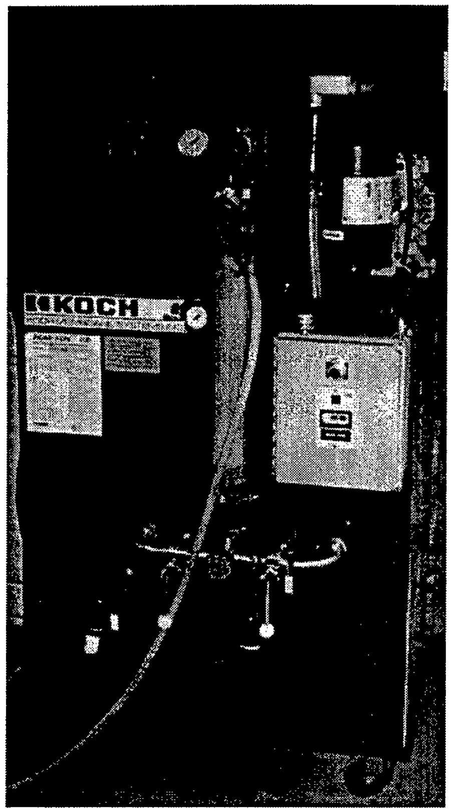

Figure IV-4. Photograph of the Membrane Ultrafiltration Unit.

Figure IV-5 is a photograph of the ClaySorb unit that was used in this test program. The ClaySorb unit consisted of a 55-gallon stainless-steel drum containing about 250 lb of the clay sorbent. The interior of the drum had a plastic lining to prevent corrosion. Wastewater inlet/outlet ports were located on the lid of the drum. The inlet port was attached to a diffuser unit that distributed the water through the filter bed. Vendor literature on the ClaySorb system is included in Appendix F-5.

f. Biotreatment

In the biotreatment approach tested, a natural mix of aerobic and anaerobic bacteria was introduced into the wastewater stream to remove O&G contamination. This mix, provided by Biosolutions Inc. had been shown capable of removing O&G and other hydrocarbons from wastewater at the wastewater treatment facilities at Luke AFB, Arizona. Certified to be non-pathogenic, the bacteria were

considered safe to be discharged from this AFB wastewater treatment system to the base sanitary sewer.

Figure IV-5. Photograph of the ClaySorb™ Unit.

Biotreatment testing in this program consisted of augmenting primary treatment processes with the addition of the bacteria mix. This bioaugmentation was used with a VTC-5 test unit at the ACWR and an SRC-M2 unit at the lagoon. A 5-gallon container of bacteria in water, and a 5-gallon container of Miracle Grow™ nutrient solution, were connected via 1/8-inch tubing to the VTC-5 and SRC-M2. Battery-operated peristaltic pumps were used to automatically meter the bacteria and nutrients to each separator. The 5-gallon containers lasted for the entire two months of testing. The vendor recommended allowing between 45 and 60 days for the bacteria to establish active colonies. However, because the duration of this test program did not permit this much time, initial booster doses of the bacteria were added to the units. The tanks were continuously aerated using a small submersible electrically-operated airpump. This measure was taken to prevent the formation of anaerobic conditions and increase aerobic activity. However, because the water in the tanks was exchanged frequently, this aeration proved to be redundant. Figure IV-6 is a

photograph of the biotreatment set-up at the lagoon. At the ACWR location, the bioaugmented VTC-5 unit was installed in addition to the VTC-5 unit described in Section IV.B.2.c. Appendix F-6 includes vendor literature on the biotreatment system.

Figure IV-6. Photograph of the Biotreatment Unit at the Dover AFB Lagoon.

g. Chemical Treatment

Chemical treatment of oily wastewater is generally conducted in two steps. First, a demulsifier is added to break down the stable oil emulsion. After destabilization, a flocculant is added to coagulate and flocculate the destabilized emulsion. A number of vendors provide chemical treatment technologies. However, chemical treatment methods are very contaminant-specific. Laboratory-scale feasibility tests on the wastewater samples are usually required before effective formulations for the demulisfying and flocculating agent can be chosen.

Three vendors were contacted, and samples of their demulsifying and flocculating agents were obtained for limited onsite exploratory testing. Samples of ACWR washwater were sent to one vendor — Midwest Custom Chemicals, Inc. — for vendor testing. After conducting these tests, the vendor provided 1-L sample bottles of a demulsifying agent, termed WEB 3, and a flocculating agent, termed WEB 40A. WEB 3 is a blend of cationic surfactants in water that aids the demulsification of oils in water.

WEB 40A is a blend of anionic polymers in water. Once oils in water are demulsified by WEB 3, WEB 40A is used as the flocculant and clarifier.

The vendor also supplied operating data sheets outlining the quantities of each chemical required per volume of wastewater. The addition of each chemical to yield wastewater concentrations of between 250 and 1,000 ppm was required depending on the wastewater O&G concentration. Vendor data sheets and literature are included in Appendix F-7.

ACWR washwater samples were not sent to the two other vendors, as samples of their agents were not nearly as effective as the WEB chemicals in the onsite exploratory testing. Thus, further testing was not performed with these chemicals.

The baseline SRC-M2 unit was used during the second part of the test program (July 1997) as a mixing and clarifying tank for the chemical demulsification studies. Effluent from the PC primary treatment unit was collected in the first chamber of the SRC-M2 unit. The demulsifying chemical, WEB 3A, was added and thoroughly mixed. The water from the first chamber overflowed into the second chamber where the flocculating agent, WEB 40, was added and mixed. The discharge pipe from this chamber was connected to a fine fabric filter that filtered out the flocculated suspended solids (floc) before final discharge. Some influent wastewater samples taken directly from the ACWR were also collected in 1-L jars and treated with WEB 3A and WEB 40 directly.

C. TEST SITE DESCRIPTION

Dover AFB was selected as the site for evaluation of the O/W separation technologies. Various aircraft, ground support equipment, and support vehicle maintenance activities occur at different Dover AFB facilities. These activities are serviced by 29 O/W separators. For this test program, four of the 29 separators were selected as the technology evaluation sites. The four sites were:

1. The O/W separator housed in Building 583, which services both the inside and outside ACWR
2. The O/W separator servicing the vehicle wash rack (VWR)

3. The O/W separator servicing the jet engine test cell (JETC)

4. The outdoor lagoon system. Effluent streams from various O/W separators on the base, including the ones in 1 and 2 above, are collected in a large holding pond before being discharged into the county sewer. The holding pond is known as the lagoon.

These four sites are described in the following subsections.

1. ACWR O/W Separator

C-5 transport aircraft are washed at Dover AFB in two ACWRs. The washwater discharge from these wash racks is processed by an SGS housed in Building 583. The separator is an open, ground-level tank, with area dimensions of 19 feet by 12 feet, and a variable depth of between 12 and 15 feet. The operating capacity of the tank is 10,000 gallons. Figures IV-7 and IV-8 are schematics of this O/W separator; Figure IV-9 is a corresponding photograph.

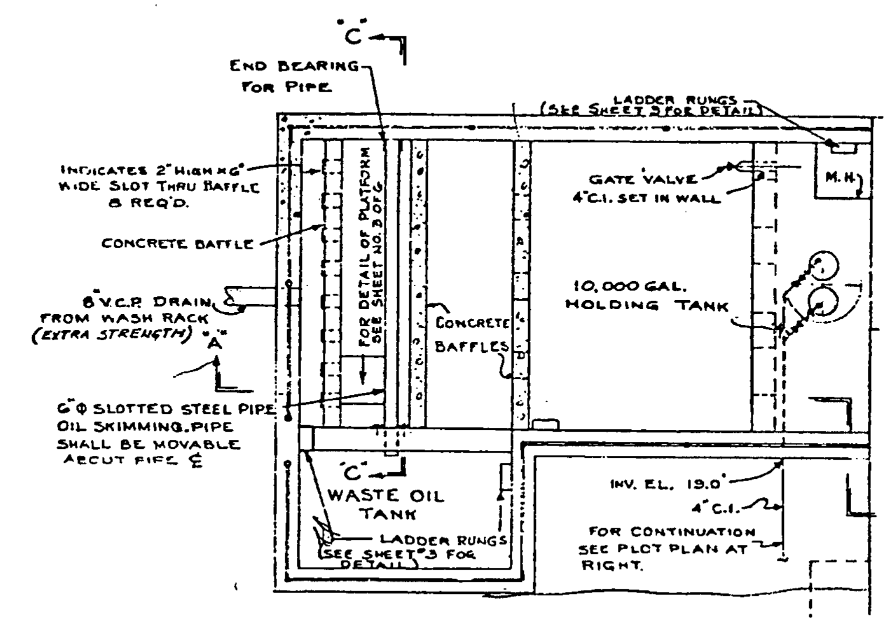

Figure IV-7. Plan View of the Building 583 O/W Separator.

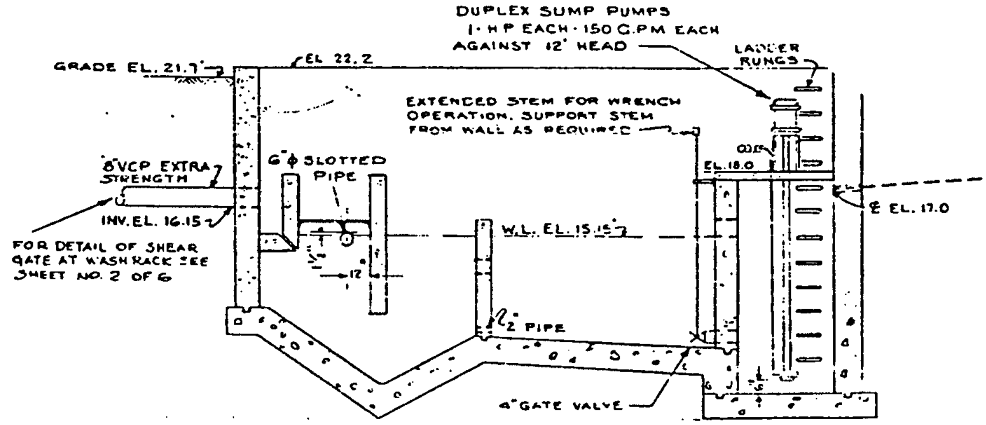

Figure IV-8. Elevation View of the Building 583 O/W Separator.

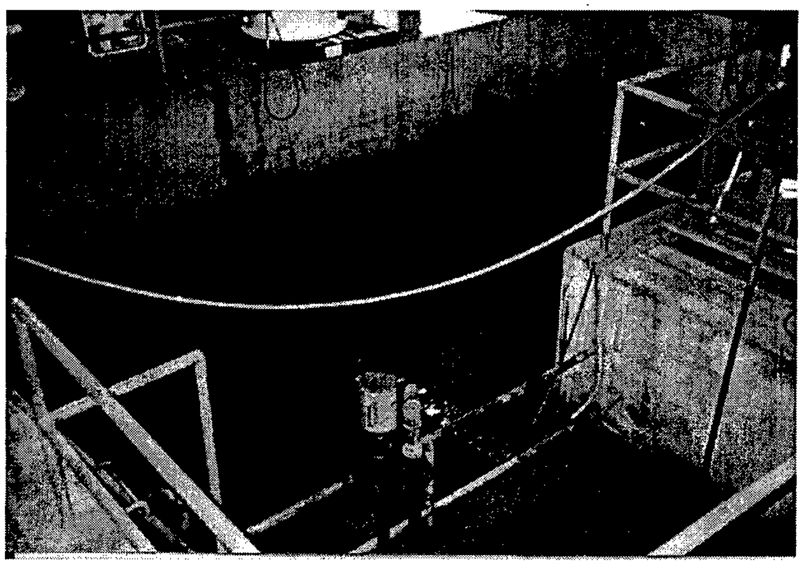

Figure IV-9. Photograph of the Building 583 O/W Separator.

As shown in Figure IV-7, the Building 583 O/W separator is divided into four sections. The washwater discharge from the outside ACWR flows into the first compartment of the separator through an 8-inch clay pipe. Wash water from the inside ACWR also flows into the first compartment but through a 10-inch clay-pipe. Figure IV-8, the elevation view of the separator, also shows the flow scheme. Most of the free oil is removed in the second two compartments. The oil layer formed on the top

is directed into a waste oil tank (see Figure IV-7). The wastewater then flows into the final compartment from which it overflows into a lift-station to be discharged into the drain leading to the lagoon system.

A typical aircraft washing cycle produces 20,000 to 25,000 gallons of wastewater over a 4- to 6-hour period. Figure IV-10 shows the wastewater flowrate profile through the O/W separator during a typical aircraft washing event. On an average, two to three aircraft are washed per week. Typically, only one ACWR is operating at a time. Normally, the inside ACWR is used exclusively during the colder months of the year.

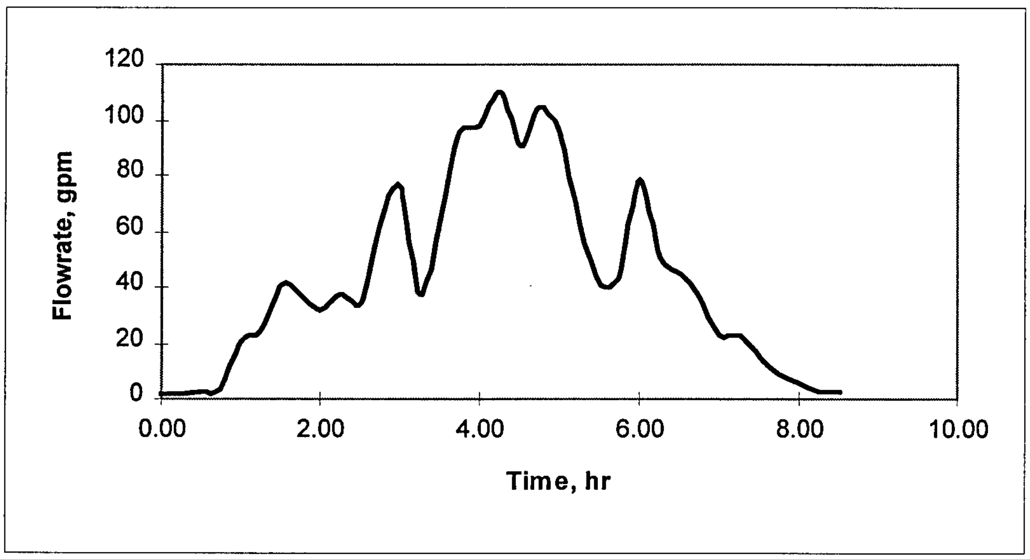

Figure IV-10. Typical ACWR Wastewater Discharge Flowrate Profile.

2. VWR and JETC O/W Separators

The VWR is serviced by a 1,000-gallon capacity O/W separator. Between 100 and 500 gallons of washwater pass through this separator daily. Most of the separation occurs in a holding tank for the lift-station at the end of the separator. Inspection of this lift-station holding tank revealed a layer of light fuel oil on the washwater with a depth of at least 18 inches. The washwater from the lift-station is pumped to the outdoor lagoon system.

The O/W separator servicing the JETC in Building 613 is a 500-gallon capacity SGS installed underground. Between 50 and 100 gallons of washwater are produced per engine test cycle. On average, one to two engines are tested per week. This separator usually encounters hydraulic fluid, which is weakly dispersed in the washwater and is easily separated. Visual inspection of the JETC O/W separator showed a rather uncontaminated layer of hydraulic fluid floating on the contained washwater. The top layer of the hydraulic fluid overflows into a waste oil tank. Oil from the waste oil tank is recovered periodically by a contractor.

3. Lagoon System

The lagoon is a final holding tank/separator for the various separator effluent streams before they are discharged into the county sewer line. Figure IV-11 is a photograph of this lagoon system. It consists of two separate end-to-end rectangular pools, each of which is approximately 20 feet wide by 40 feet long. Normally, only one pool is in operation at a time. A 3-inch flexible hose is used to direct the incoming wastewater into either of the two pools. This hose is located where the two pools meet. The surface oil is wind-driven to the end opposite of the water discharge side where it is skimmed into a waste oil tank. The wastewater overflows into a drain and, before it is discharged into the county sewer line, is treated by a set of FRAM™ filters to remove any residual O&G.

The largest fraction of the wastewater entering the lagoon is from the ACWR O/W separator. About 80,000 gallons of ACWR washwater are discharged into the lagoon per week. The total discharge to the lagoon from the other base sources is between 10,000 and 15,000 gallons per week.

D. TEST PLAN

The above seven technologies were tested with actual oily wastewater streams generated by different facilities at Dover AFB. The generating facilities included two ACWRs, a JETC, VWR, and a lagoon system. These facilities (excluding the lagoon) are typical of those found at most AFBs. At Dover AFB, the largest generators of oily wastewater are the aircraft washing operations. They produce nearly 70 percent of the

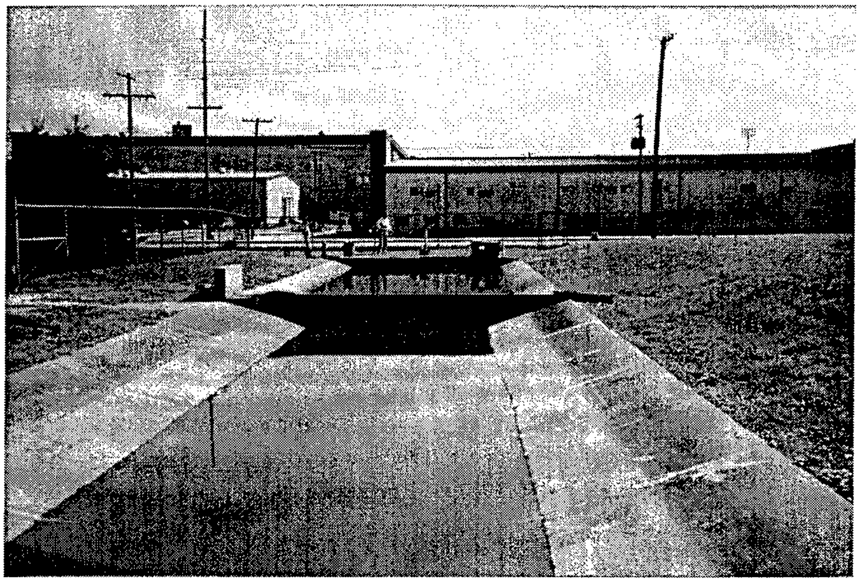

Figure IV-11. Photograph of the Lagoon System.

total discharge from the existing O/W separators to the county sewer. Therefore, the main testing was conducted at the O/W separator servicing the two base ACWRs.

The performance of the test-separators was evaluated by varying the following two critical parameters:

- Residence time of the oily wastewater in the separator
- Concentration of the oil in the wastewater

Testing was performed by taking a slipstream from the inlet to the existing O/W separator and manifolding representative sample streams to the individual treatment units. A common influent sample was taken at the manifold. Individual effluent samples were taken at the outlet of each treatment unit. One liter glass mason jars with screw caps were used to collect the samples, which averaged approximately 700 mL each.

All test samples were analyzed for O&G by EPA Method 1664. Other analytical procedures performed on selected samples included estimation of total organic carbon (TOC) by EPA Method 415.2, measuring surfactant levels as methylene blue active substances (MBAS) by EPA Method 425.1, measuring chemical oxygen demand (COD)

by EPA Method 410.4, and the quantity of filterable solids (QFS) by gravimetry. A field laboratory for the analysis of O&G and QFS was set up on-site. TOC, MBAS, and COD analyses were performed by Sequoia Analytical in Redwood City, California.

The complete test plan is included as Appendix E.

E. TEST RESULTS

The test report details quantitative test program results. Of technologies tested, overall results showed effluent oil concentrations were highest for the baseline SGS process, followed by the SGS with coalescers, and SGS with coalescers and biotreatment in order. Organoclay treatment, ultrafiltration and chemical demulsification produced the lowest effluent O&G concentrations. Test results from the treatment of actual ACWR wastewater are summarized in Table IV-2. (See Section IV.E.2.a for the definition of removal efficiency [RE]). Table IV-3 provides a similar study for a series of tests in which the ACWR wastewater was spiked to higher O&G concentrations.

TABLE IV-2. REMOVAL EFFICIENCY (RE) FOR THE ACWR TESTS.

Separation System	RE Range (%)	Average RE (%)	Median RE (%)
Baseline SGS	~74	26	26
SGS with vertical tube coalescers	~55	30	34
SGS with slant rib parallel plate coalescers	~61	29	29
Biotreatment	39-79	67	71
Organoclay filtration	79-96	88	89

TABLE IV-3. REMOVAL EFFICIENCY (RE) FOR THE OIL SPIKE ACWR TESTS.

Separation System	RE Range (%)	Average RE (%)	Median RE (%)
SGS with vertical tube coalescers	30-99	72	74
SGS with slant rib parallel plate coalescers	33-99	71	73
Biotreatment	37-98	71	72
Organoclay filtration	90-99.9	97	98

Little difference was seen in the separation efficiency, the required operating attention, or the cleaning requirements for the SGS processes with or without coalescers. However, it must be noted that the present test program was not designed to evaluate the long-term effects of sludge build-up in the test units. Long-term operation will most likely cause sludge build-up in the coalescing media, requiring that the media be cleaned. Of the different coalescing media geometries and sizes used in this test program, the vertical-tube coalescers will require the least effort in cleaning because of their relatively open-mesh configuration. The parallel-plate coalescing media, in contrast, will be relatively difficult to clean, the level of difficulty increasing with decreasing plate spacing.

In terms of performance, all of the SGS processes, with or without coalescers, were fairly efficient in removing the free oil in the influent. The organoclay filtration system was used to treat effluent from the SGS as well as raw influent taken from the manifold system. The organoclay filtration system consistently reduced O&G concentrations below 20 mg/L, producing visibly clear water. Nevertheless, although organoclay filtration can be used as a primary separation system, the process is more cost effective when preceded by a primary treatment device that removes free oil. Several options exist for disposal of the clay, however, disposal is an economic concern.

Biotreatment was conducted by connecting a nutrient source, oxygen source, and bacteria source to a SGS with vertical tube coalescers. In the ACWR tests, the influent flowrate to the biosystem was about half that fed to the other manifolded systems as the bacteria required sufficient residence time to digest the O&G. However, the biotreatment process effluent was clearer and the process tanks were cleaner and less odorous, containing markedly less residual surface oil than the other SGS process tanks. O&G spikes were also repressed by the biotreatment system.

Membrane ultrafiltration was used to treat several different wastewater streams. The membrane system reduced O&G concentrations from all sources to below 10 mg/L producing visibly clear effluent. The membrane required cleaning after each use and could not be allowed to dry. As expected, the membrane technology was more difficult

to operate and more time consuming to clean than the other technologies, thereby requiring closer operator attention. Chemical addition to destabilize emulsions was also used with good success. After chemical demulsifiers were added to the baseline SGS, the effluent from the separator, after filtration to remove the flocculant, was clear with O&G concentrations below 20 mg/L.

Neither membrane ultrafiltration nor chemical demulsification are recommended for use by the AF, as these processes require substantial maintenance and continuous operator attention. Chemical demulsification also incurs the ongoing cost of chemicals and flocculant removal as well as equipment costs for stirring tanks and metering pumps. Membrane ultrafiltration incurs the ongoing costs of electricity and suffers from limited processing capacity, frequent downtime for cleaning, and periodic membrane replacement costs. Membrane ultrafiltration is an ideal technology to use if the treated wastewater is going to be recycled. However, for discharge quality effluent, membrane separation and chemical demulsification are unnecessarily complex and expensive.

Another technology of interest, one potentially applicable to both O/W separation and demulsification, is the air-sparged hydrocyclone (ASH). Although the ASH was not tested in this test program, it has been demonstrated at the pilot-scale in the AF[IV-3] (see also Appendix D).

Operating data for the O/W separator processes tested, and analytical laboratory data for the samples collected, are separately discussed in the following subsections.

1. Process Operating Data

As noted in Appendix E, the field test program was conducted in two parts between May 27 and July 17, 1997. A total of 25 test runs were completed on the setup in Building 583 over this time period. Each test fell into one of the following three categories:

1. Dynamic tests on ACWR discharge streams: These were performed in Building 583 during actual washing cycles on real-time ACWR discharge streams. Both primary and secondary treatment processes were evaluated in these tests. Tests were performed over a total of 10 aircraft wash cycles. Six of the wash cycles occurred in the outside wash rack

during Part 1 of the test program. In Part 2 of the test program, four wash cycles occurred in the inside wash rack.

2. <u>Static tests</u>: The test washwater stream was drawn from the influent holding tank of the O/W separator in Building 583.

3. <u>Oil-spike tests</u>: In these tests, oil was spiked into the influent stream to the test separators to evaluate the effect of high-concentration slugs of oily water on the separation efficiency. These tests were performed both under dynamic (one test) and static (10 tests) conditions. These tests were conducted during the second part of the field tests. Vegetable oil and motor oil were used for spiking.

Tables IV-4 and IV-5 summarize the process operating data for all tests performed on the Building 583 setup. Table IV-4 is the operating data summary for tests conducted during Part 1 of the field test program; Table IV-5 is the corresponding summary of the operating data for Part 2 of the test program. For all tests, the influent pump and manifold pressure were 20 psi.

As indicated in Table IV-4, during Part 1 of the test program, four primary treatment processes were connected to the manifold system described in Section 4.1 for the entire Part 1 test period, which encompassed 10 tests: the baseline SGS, PressureClear, VTC-5, and biotreatment processes. For the dynamic tests, Tests 1-2, 1-3, and 1-5, the ClaySorb system was operated as a secondary treatment process treating a slipstream of the discharge from the PressureClear process. For Tests 1-6 through 1-10, the ClaySorb system was connected to the ACWR effluent manifold and operated as a primary treatment process.

For Part 2 of the test program, the baseline SGS tank system was relocated to the discharge of the PressureClear unit, and served as the process tanks for the chemical treatment process operated as a secondary treatment. The other four processes, PressureClear, VTC-5, biotreatment, and ClaySorb, continued operation as primary treatment processes for the 15 tests comprising Part 2 of the program.

TABLE IV-4. OPERATIONS DATA — PART 1.

Test Number	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10
Date	6/4/97	6/6/97	6/8/97	6/9/97	6/11/97	6/12/97	6/14/97	6/15/97	6/16/97	6/17/97
Test Type	Static	Dynamic	Dynamic	Static	Dynamic	Static	Dynamic	Dynamic	Dynamic	Static
Aircraft #	—	60013	31285	—	40061		50007	50009	60020	
Test Period	0830-1050	0400-1007	0415-0900	1330-1530	0430-0950	0820-1030	0420-1020	0445-0845	0430-0845	0825-1020
Test Duration, min	140	367	285	120	320	130	360	240	225	115
Average Flowrate, gpm										
1. PressureClear	0.90	0.90	1.00	1.00	1.00	1.10	1.50	1.75	1.90	1.90
2. ClaySorb	—	—	—	—	—	0.1	0.45	0.4	0.4	0.4
3. VTC-5	0.50	0.63	0.55	0.50	0.55	0.60	1.50	1.85	1.65	1.50
4. Baseline SGS	1.00	1.00	1.00	0.90	1.00	1.00	1.50	1.75	1.90	1.90
5. Biotreatment (Building 583)	—	—	0.10	0.15	0.10	0.10	0.20	1.75	0.20	0.20
6. Biotreatment (Lagoon)	—	—	0.20	—	0.20	—	0.20	0.20	0.20	0.20
Residence Time, min										
1. PressureClear	89	89	80	80	80	73	53	46	42	42
2. ClaySorb	—	—	—	—	—	550	120	140	140	140
3. VTC-5	90	71	82	90	82	75	30	24	27	30
4. Baseline SGS	75	75	75	83	75	75	50	43	40	40
5. Biotreatment (Building 583)	—	—	450	300	450	450	220	26	220	220
6. Biotreatment (Lagoon)	—	—	380	—	380	—	380	380	380	380
Total Volume Processed, gal										
1. PressureClear	126	330	285	120	320	143	540	420	428	219
2. ClaySorb	—	—	—	—	—	13	162	96	90	46
3. VTC-5	70	231	157	60	176	78	540	444	371	173
4. Baseline SGS	140	367	285	108	320	130	540	420	428	219
5. Biotreatment (Building 583)	—	—	29	18	32	13	72	420	45	23
6. Biotreatment (Lagoon)	—	—	19	—	39	—	132	72	75	27
ACWR O/W Separator										
Mean Flowrate, gpm	—	30	38	—	43	—	12	20	19	—
Peak Flowrate, gpm	—	92	106	—	111	—	33	53	53	—
Total volume processed, gal	—	20820	16112	—	22812	—	4400	7926	6690	—

TABLE IV-5. OPERATIONS DATA — PART 2.

Test Number	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13	2-14	2-15
Date	7/9/97	7/10/97	7/10/97	7/11/97	7/11/97	7/11/97	7/12/97	7/12/97	7/13/97	7/13/97	7/14/97	7/14/97	7/14/97	7/15/97	7/15/97
Test Type	Oil Spike	Oil Spike	Oil Spike	Dynamic	Dynamic	Dynamic	Dynamic	Oil Spike	Dynamic	Oil Spike	Oil Spike	Oil Spike	Oil Spike	Oil Spike	Oil Spike
Influent Source	O/W Sep	O/W Sep	O/W Sep	ACWR	ACWR	ACWR	ACWR	ACWR	ACWR	O/W Sep	O/W Sep	O/W Sep	O/W Sep	O/W Sep	O/W Sep
Test Period	0600-0830	0620-0945	1340-1537	0500-0750	0758-0821	0821-0930	0430-0930	0915-1030	0447-0845	0900-1100	0615-0730	0730-1000	1000-1130	0630-0815	0815-1000
Test Duration, min	150	205	117	240	241	242	300	75	238	120	285	285	285	210	210
Spike Oil	Vegetable Oil	Vegetable Oil	Vegetable Oil	—	Vegetable Oil	Vegetable Oil	—	Vegetable Oil	—	Vegetable Oil	Motor Oil	Motor Oil	Motor Oil	Motor Oil	Motor Oil
Spike Volume, ml	900	450	450	—	465	465	—	465	—	465	250	250	250	250	250
Spike Duration, min	22	22	11	—	23	8	—	10	—	20	30	30	30	30	30
Post Spike Influent Source	O/W Sep	O/W Sep	O/W Sep	—	ACWR	ACWR	—	Makeup Water	ACWR	O/W Sep	O/W Sep	O/W Sep	Makeup Water	Makeup Water	Makeup Water
Average Flowrate, gpm															
1. PressureClear	0.9	0.9	0.9	1.8	1.8	1.0	1.0	1.0	1.0	1.0	1.0	1.8	1.8	2.0	1.8
2. ClaySorb	0.2	0.2	0.2	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.4	—	0.4
3. VTC-5	0.5	0.5	0.5	1.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0
5. Biotreatment	0.4	0.4	0.4	1.5	1.5	0.4	0.4	0.4	0.2	0.2	0.4	0.2	0.2	0.2	0.2
Total Flow Through Manifold, gpm	2.0	2.0	2.0	5.2	5.2	2.1	2.1	2.1	1.9	1.9	2.1	3.4	3.4	3.2	3.4
Total Recirculation Flow, gpm	—	5.4	2.0	2.0	2.0	2.0	3.0	1.2	2.0	3.0	3.4	3.7	3.6	3.6	3.6
Residence Time, min															
1. PressureClear	89	89	89	44	44	80	80	80	80	80	80	44	44	40	44
2. ClaySorb	280	280	280	140	140	280	280	280	280	280	280	140	140	—	140
3. VTC-5	90	90	90	30	30	90	90	90	90	90	90	45	45	45	45
5. Biotreatment	110	110	110	30	30	110	110	110	220	220	110	220	220	220	220
Total Volume Processed During Spiking, gal															
1. PressureClear	20	20	10	—	41	8	—	10	—	20	30	54	54	60	54
2. ClaySorb	4	4	2	—	9	2	—	2	—	4	6	12	12	—	12
3. VTC-5	11	11	6	—	35	4	—	5	—	10	15	30	30	30	30
5. Biotreatment	9	9	4	—	35	3	—	4	—	4	12	6	6	6	6
Total Volume Processed, gal															
1. PressureClear	135	185	105	432	434	242	300	75	238	120	285	513	513	420	378
2. ClaySorb	30	41	23	96	96	48	60	15	48	24	57	114	114	—	84
3. VTC-5	75	103	59	360	362	121	150	38	119	60	143	285	285	210	210
5. Biotreatment	60	82	47	360	362	97	120	30	48	24	114	57	57	42	42
ACWR O/W Separator															
Mean Flowrate, gpm	—	—	—	43	—	—	38	—	60	—	—	—	—	—	—
Peak Flowrate, gpm	—	—	—	125	—	—	132	—	174	—	—	—	—	—	—
Total Volume Processed,, gal	—	—	—	23784	23785	23786	20410	—	22,906	—	—	—	—	—	—

In addition to the dynamic and static tests with ACWR washwater listed in Tables IV-4 and IV-5, a series of nine tests was performed using the membrane ultrafiltration system during Part 1 of the program. In these tests, the unit's process water tank was charged with wastewater from the JETC, the lagoon, or the VWR; ACWR washwater from the O/W separator holding tank; or effluent from the PressureClear unit. After charging, process wastewater was recirculated through the ultrafiltration system, with makeup wastewater added to replace the cleaned water discharge from the system, until a target volume of wastewater of between 20 and 60 gallons had been processed. At the conclusion of Part 1, the unit was returned to the vendor.

Experience with the membrane system tested showed that it required frequent cleaning in order to retain high process flowrate capability. Cleaning required the complete emptying of the process tank and rinsing of the system with clean tap water until the membrane returned to its original color and effluent was clear. The process vendor recommends the use of warm water with a special detergent. However, in this test program it was found to be possible to return the system to adequate levels of cleanliness and process flowrate with tap water alone. Each cleaning took an average of 1 hour. This time requirement may have been shortened via the use of the recommended warm water and detergent. While the system was fairly simple to assemble, operate, and maintain, it did require nearly continuous operator attention.

The biotreatment unit setup at the lagoon was tested at a constant influent flowrate of 0.2 gpm, giving a 380-minute treatment residence time. Test periods were 3 to 5 hours long. These tests differed from the biotreatment tests performed on the setup in Building 583, which had influent flowrate, and therefore treatment residence time, as a test variable. Fourteen biotreatment tests were performed at the lagoon location.

As noted above, the chemical treatment system was operated as a secondary treatment process during Part 2 of the program. Ten tests treating the PressureClear process discharge were completed. However, at the conclusion of the test program, the chemical treatment process was fed ACWR discharge and run as a primary treatment process for two tests.

2. Analytical Results Summary

Test analytical results are summarized and discussed, by test analyte, in the following subsections.

a. Oil and Grease (O&G)

Table IV-6 summarizes the O&G data for the various primary treatment O/W separator systems tested in Building 583. The influent and effluent O&G concentrations given in the table are averages over the duration of each test run. Table IV-7 lists the O&G removal efficiency (RE) for each test; RE is defined as:

$$RE, \% = 100 \cdot \frac{Influent\ Concentration - Effluent\ Concentration}{Influent\ Concentration} \qquad (IV\text{-}1)$$

In those cases in which the effluent concentration was greater than the corresponding influent concentration, RE was defined to be 0. Negative REs occur as testing artifacts because the required instantaneous grab sampling methodology for O&G cannot accommodate the time scale and capacitance of the process. Treatment residence times (wherever applicable) are also noted in Table IV-7.

Table IV-8 summarizes the O&G data with corresponding REs for the biotreatment process tests performed at the lagoon. As noted above, all lagoon biotreatment tests were performed with a 380-minute treatment residence time.

Table IV-9 summarizes the O&G data with corresponding REs for the membrane ultrafiltration system. Treatment residence times varied for this system, which recirculated the wastewater charge until a target volume of wastewater had been processed.

Table IV-10 summaries the O&G data with corresponding REs for the chemical treatment system tested during Part 2 of the program. For all but the last day of testing, the chemical treatment process was tested as a secondary treatment treating the effluent from the PressureClear system. Two tests were performed on the last test day using the system to treat primary ACWR effluent.

TABLE IV-6. O&G ANALYSIS DATA SUMMARY FOR THE PRIMARY TREATMENT PROCESS TESTS PERFORMED IN BUILDING 583.

Test No.[a]	Test Type[a]	Influent O&G Concentration (mg/L)	Effluent O&G Concentration (mg/L)				
			Baseline SGS	VTC-5	PressureClear	Biotreatment	ClaySorb
1-1	Static	24	25	22	25	—	—
1-2	Dynamic	49	29	22	19	—	—
1-3	Dynamic	47	28	23	21	20	—
1-4	Static	38	33	22	29	13	—
1-5	Dynamic	44	32	24	24	10	—
1-6	Static	48	55	56	52	10	2
1-7	Dynamic	46	34	33	22	11	6
1-8	Dynamic	18	16	16	23	11	—
1-9	Dynamic	38	28	23	25	12	8
1-10	Static	47	12	37	38	12	4
2-1	Oil spike, static	1,550	—	30	270	55	40
2-2	Oil spike, static	177	—	49	60	50	2
2-3	Oil spike, static	388	—	114	137	99	39
2-5	Oil spike, static	1,400	—	162	140	148	30
2-6	Oil spike, static	6,170	—	135	132	112	7
2-7	Dynamic	113	—	69	76	71	2
2-8	Oil spike, dynamic	1,740	—	9	16	43	1
2-9	Dynamic	117	—	—	—	44	—
2-10	Oil spike, static	244	—	76	74	74	8
2-11	Oil spike, static	323	—	72	82	73	29
2-12	Oil spike, static	—	—	—	19	82	—
2-13	Oil spike, static	166	—	42	23	82	2
2-14	Oil spike, static	126	—	88	75	64	—
2-15	Oil spike, static	165	—	80	98	72	—

[a]See Tables IV-4 and IV-5.

TABLE IV-7. O&G REMOVAL EFFICIENCIES FOR THE PRIMARY TREATMENT PROCESS TESTS PERFORMED IN BUILDING 583.

			Baseline SGS		VTC-5		PressureClear			Biotreatment		ClaySorb	
Test No.[a]	Test Type[a]	Influent O&G Concentration (mg/L)	Treatment Residence Time (min)	O&G Removal Efficiency (%)	Treatment Residence Time (min)	O&G Removal Efficiency (%)	Coalescing Media Nominal Vendor Size (in)	Treatment Residence Time (min)	O&G Removal Efficiency (%)	Treatment Residence Time (min)	O&G Removal Efficiency (%)	Treatment Residence Time (min)	O&G Removal Efficiency (%)
1-1	Static	24	75	0	90	8	0.75	89	0	—	—	—	—
1-2	Dynamic	49	75	41	71	55	0.75	89	61	—	—	—	—
1-3	Dynamic	47	75	40	82	51	0.75	80	55	450	57	—	—
1-4	Static	38	83	13	90	42	0.75	80	24	300	66	—	—
1-5	Dynamic	44	75	27	82	46	0.75	80	45	450	77	—	—
1-6	Static	48	75	0	75	0	0.75	73	0	450	79	552	96
1-7	Dynamic	46	50	26	30	28	0.75	53	52	220	76	120	87
1-8	Dynamic	18	43	11	24	11	0.75	46	0	26	39	—	—
1-9	Dynamic	38	40	26	27	40	0.75	42	34	220	68	140	79
1-10	Static	47	40	74	30	21	0.75	42	19	220	74	140	91
2-1	Oil spike, static	1,550	—	—	90	98	1.0	89	83	110	96	280	97
2-2	Oil spike, static	177	—	—	90	72	1.0	89	66	110	72	280	99
2-3	Oil spike, static	388	—	—	90	71	1.0	89	65	110	74	280	90
2-5	Oil spike, static	1,400	—	—	30	88	1.0	44	90	30	89	140	98
2-6	Oil spike, static	6,170	—	—	90	98	1.0	80	98	110	98	280	99.9
2-7	Dynamic	113	—	—	90	39	1.0	80	33	110	37	280	98
2-8	Oil spike, dynamic	1,740	—	—	90	99	1.0	80	99	110	98	280	99
2-9	Dynamic	117	—	—	—	—	—	—	—	220	62	—	—
2-10	Oil spike, static	244	—	—	90	69	0.5	80	70	220	70	280	97
2-11	Oil spike, static	323	—	—	90	78	0.5	80	75	110	77	280	91
2-13	Oil spike, static	166	—	—	45	75	0.5	44	86	220	51	140	99
2-14	Oil spike, static	126	—	—	45	30	0.5	40	41	220	49	—	—
2-15	Oil spike, static	165	—	—	45	51	0.5	44	41	220	56	—	—

[a]See Tables IV-4 and IV-5.

TABLE IV-8. O&G ANALYSIS DATA SUMMARY FOR THE BIOTREATMENT SYSTEM TESTED AT THE LAGOON.

Test Date	O&G Concentration (mg/L)		Removal Efficiency (%)
	Influent	Effluent	
6/8/97	45	52	0
6/11/97	44	24	45
6/12/97	168	28	83
6/13/97	43	15	65
6/15/97	248	23	91
6/16/97	33	28	15
6/17/97	65	30	54
7/10/97	46	12	74
7/11/97	93	12	87
7/12/97	54	21	50
7/13/97	49	83	0
7/14/97	56	40	29
7/15/97	62	53	15
7/16/97	75	30	60

TABLE IV-9. O&G ANALYSIS DATA SUMMARY FOR THE MEMBRANE SEPARATION SYSTEM TESTS.

Test Date	Wastewater Feed	O&G Concentration (mg/L)		Removal Efficiency (%)
		Influent	Effluent	
6/5/97	Lagoon	92	5	95
6/6/97	VWR	19	3	84
6/8/97	PC effluent	21	4	81
6/9/97	PC effluent	29	4	86
6/10/97	Lagoon	33	3	91
6/10/97	JETC	2550	3	99
6/11/97	JETC	44	4	91
6/11/97	JETC	1090	7	99
6/12/97	Building 583 O/W separator holding tank	48	4	92

TABLE IV-10. O&G ANALYSIS DATA SUMMARY FOR THE CHEMICAL TREATMENT SYSTEM TESTS.

Test No.[a]	Test Date[a]	Influent Stream	O&G Concentration (mg/L)		Removal Efficiency (%)
			Influent	Effluent	
2-2	7/10//97	PC effluent	60	4	93
2-3	7/10/97	PC effluent	137	3	98
2-5	7/11/97	PC effluent	140	11	92
2-6	7/11//97	PC effluent	132	4	97
2-7	7/12/97	PC effluent	76	4	95
2-10	7/13/97	PC effluent	74	6	92
2-11	7/14/97	PC effluent	82	5	94
2-13	7/14/97	PC effluent	23	10	57
2-14	7/15/97	PC effluent	75	5	93
2-15	7/15/97	PC effluent	98	3	97
—	7/16/97	ACWR effluent	147	16	89
—	7/16/97	ACWR effluent	98	4	96

[a]See Table IV-4.

Finally, Table IV-11 summarizes the O&G data and REs for the three tests of the ClaySorb process as a secondary treatment of PressureClear system discharge performed early in Part 1 of the program.

TABLE IV-11. O&G ANALYSIS DATA SUMMARY FOR THE CLAYSORB SYSTEM AS SECONDARY TREATMENT.

Test No.[a]	Test Date[a]	Influent Stream	O&G Concentration (mg/L)		Treatment Residence Time (min)	Removal Efficiency (%)
			Influent	Effluent		
1-2	6/6/97	PC effluent	19	3	250	84
1-3	6/8/97	PC effluent	21	4	250	81
1-5	6/11/97	PC effluent	24	2	250	92

[a]See Table IV-4.

of O&G in a water sample. As discussed in Appendix E, Section D.2, Method 1664, the O&G analysis starts with filtration of the water sample through a set of filters that removes the mechanically dispersed emulsion fraction plus any suspended solids in the water. Subsequent hexane extraction of the filtration system separates out the O&G portion of the material captured by the filtration system. Thus, Method 1664 gives a measure of the mechanically dispersed O&G.

Chemically emulsified O&G will likely pass through this initial filtration step, however, and thereby be lost to the analytical procedure. Thus, as an estimate of this chemically emulsified O&G fraction, select filtered water samples were subjected to the purge-and-trap FID analysis procedure by Method 415.2, as discussed in Appendix E, Section D.2. One unfiltered water sample was also subjected to TOC analysis. The sum of the Method 1664 and Method 415.2 analysis results for a given sample was used as an approximation of the total (mechanically plus chemically dispersed) O&G.

The ClaySorb and chemical treatment processes likely added organic carbon content to their effluents because both systems involve processing with organic chemicals. The biotreatment process may also have added organic carbon content to its effluent stream in the form of microbial wash-out. Detergents also can add to the organic content of respective samples, as detergents consist of long-chain organic compounds.

c. Surfactants: Methylene Blue Active Substances (MBAS)

The quantity of detergent in samples of the ACWR discharge influent stream was estimated by measuring their anionic surfactant contents as MBAS. The MBAS data are summarized in Table IV-13.

TABLE IV-12. TOC ANALYSIS DATA SUMMARY.

Sample	TOC Content (mg/L)	Method 1664 O&G Content (mg/L)	Total O&G Content (M415.2 + Method 1664 O&G) (mg/L)
ACWR Discharge (Treatment Process Influent)			
Test 1-3	52	47	99
Test 1-5	53	44	97
Test 2-16	230	118	348
Test 2-16 (unfiltered[a])	254	(118)[b]	372
Baseline SGS			
Test 1-3	53	28	81
Test 1-5	61	32	93
Test 1-9	100	28	128
VTC-5			
Test 1-3	63	23	86
Test 1-5	74	24	98
Test 2-7	120	69	—
Test 2-9	155	(NA)[c]	—
PressureClear			
Test 1-3	58	21	79
Test 1-5	45	24	69
Test 2-7	110	76	186
Biotreatment (Building 583)			
Test 1-3	70	20	90
Test 1-5	51	10	61
Test 1-8	88	11	99
Test 2-9	105	44	149
Biotreatment (Lagoon)			
6/8/97	96	52	148
6/11/97	93	24	117
7/13/97	105	83	188
ClaySorb			
Test 1-2[d]	100	3	103
Test 1-5[d]	72	2	74
Test 1-6	400	2	402
Test 1-7	210	6	216
Test 1-9	72	8	80
Membrane Ultrafiltration			
6/5/97 (Lagoon water)	36	5	41
6/8/97 (PC effluent)	59	4	63
6/10/97 (Lagoon water)	67	3	70
6/10/97 (JETC discharge)	243	3	246
6/11/97 (JETC discharge)	275	7	282
Chemical Treatment			
Test 2-7 (PC effluent)	94	4	98
Test 2-10 (PC effluent)	170	6	176
7/16/97 (ACWR effluent)	180	16	196

[a]Raw discharge sample analyzed instead of the Method 1664 filtrate.
[b]From Test 2-16.
[c](NA) = Not analyzed.
[d]ClaySorb was secondary treatment process treating PC system effluent.

TABLE IV-13. SURFACTANT ANALYSIS DATA FOR THE ACWR DISCHARGE STREAM.

Influent Sample No.	Surfactant Concentration (mg MBAS/L)
1	8.8
2	4.6
3	6.8
4	6.0
5	5.2
Average	6.3

TABLE IV-14. COD ANALYSIS DATA SUMMARY.

Sample Set	COD (mg/L)	
	ACWR Discharge	Chemically Treated ACWR Discharge
1	1,100	440
2	450	—

d. Chemical Oxygen Demand (COD)

COD analyses were performed on three sets of samples, with all sets analyzed in triplicate. Two of the sample sets consisted of the ACWR discharge stream samples, and the third consisted of chemical treatment discharge samples. Table IV-14 summarizes these COD data.

e. Filterable Solids (FS)

The weight of the filterable solids and floc produced by the chemical treatment process applied to the ACWR discharge and the PC process effluent was measured. Table IV-15 summarizes these floc weight data.

TABLE IV-15. FILTERABLE SOLIDS IN CHEMICALLY TREATED SAMPLES.

Sample	Floc Weight (mg/L)
Test 2-14 (PC effluent)	630
Test 2-15 (PC effluent)	1,030
7/16/97 (ACWR discharge)	585
7/16/97 (ACWR discharge)	170

F. TECHNOLOGY PERFORMANCE EVALUATION

The performance of the various separation systems tested is discussed in this section. The performance evaluation focused on two criteria: oil removal efficiency (RE) and system operation and maintenance (O&M) requirements. System REs are summarized in Section 5. The field tests were performed over a period totaling 5 weeks. Although this period of time was insufficient to allow a thorough evaluation of system O&M requirements, sufficient operating familiarity was gained with the various separator systems, tested under a range of wastewater discharge conditions, to make possible reasonable forecasts of expected O&M requirements.

1. Removal Efficiencies

a. Dynamic and Static Tests with ACRW Effluent

The O&G REs achieved by the primary treatment processes in treating the ACWR discharge stream, in both dynamic and static tests, are summarized in Table IV-16. The table also notes the average efficiency, as well as the median efficiency measured for each treatment process.

TABLE IV-16. O&G REMOVAL EFFICIENCIES: DYNAMIC AND STATIC ACWR EFFLUENT TESTS.

	O&G RE[a] (%)		
Separator System	Range	Average	Median
Baseline SGS	0-74	26	26
VTC-5	0-55	30	34
PressureClear	0-61	29	29
Biotreatment	39-79	67	71
ClaySorb	79-96	88	89

[a]See Table IV-7.

The ACWR discharge stream can be characterized as a high-flow, low-concentration stream. The data in Table IV-16 show that, in the treating of this stream, the average RE of the separators with the coalescers was only slightly greater than the baseline SGS separator. However, onsite observations indicated that the VTC coalescing media imparted a "damping" effect; the separators with the coalescing media showed smaller fluctuations in the effluent O&G concentrations compared to the baseline SGS. This is reflected in a smaller range of efficiencies seen for the VTC-5 and PressureClear systems. In addition, visual observations indicated that the effluent from the separators with coalescing media was clearer compared to the effluent from the baseline SGS, suggesting better solids removal performance by the separators. Furthermore, the median of the average RE was significantly greater for the VTC-5 process compared to the baseline SGS, and only marginally better for the PressureClear process.

The data in Table IV-16 clearly show that the bioaugmentation of the VTC-5 process improved its performance substantially. The ClaySorb process gave the best REs measured, averaging 88 percent, although the ClaySorb process test data were obtained in only four tests. The static and dynamic tests did not evaluate the dependence of RE on residence time for any of the processes tested. This was because the average influent O&G concentration was low with respect to the peak concentrations. Also, because the test units were designed to mimic the actual separator, the selected operating residence time was more than sufficient for maximum removal.

b. Oil Spike Tests

Tests were performed in Part 2 of the test program (July 7 to 17, 1997) to evaluate the performance of the separators when slugs of oil were introduced into their influent streams. Table IV-17 summarizes the O&G REs achieved by the various separator systems in the oil-spike tests. As shown in the table, both the median and the average O&G REs in the oil-spike tests for the three primary treatment systems (VTC-5, PressureClear, and biotreatment with VTC-5) were comparable. The variations in the RE data (RE ranges) for each primary system were also similar. As in the

dynamic and static tests, the performance of the ClaySorb process in terms of O&G RE was uniformly better.

TABLE IV-17. O&G REMOVAL EFFICIENCIES: OIL-SPIKE TESTS.

Separator System	O&G RE (%)		
	Range	Average	Median
VTC-5	30-99	72	74
PressureClear	33-99	71	73
Biotreatment	37-98	71	72
ClaySorb	90-99.9	97	98

The RE data in Table IV-17 were for all oil-spike tests, regardless of the O/W separator process operating conditions. However, treatment residence time was varied for all processes to see whether this affected RE. Table IV-18 summarizes the O&G REs for two primary treatment systems as a function of residence time for the oil-spike tests.

As expected, the O&G RE increased with residence time for both the separation systems at both oil spiking concentrations. In addition, O&G REs were increased at the higher oil spiking levels, also as expected. However, the potential effects of variations in other possibly important performance factors, such as coalescing media size, media surface area, and separator geometry, have not been separated out of the average RE data in Table IV-18.

TABLE IV-18. AVERAGE RE AS A FUNCTION OF RESIDENCE TIME FOR THE OIL-SPIKE TESTS.

Separator System	Residence Time (min)	Average RE (%)	Residence Time (min)	Average RE (%)
Low Spiking Concentration (126-388 mg/L)				
VTC-5	45	52	90	73
PressureClear	40-45	56	80-90	69
High Spiking Concentration (1400-6170 mg/L)				
VTC-5	30	88[a]	90	98
PressureClear	44	90[a]	80-90	93

[a]One test only.

Data on the effect of coalescing media size on the RE for similar influent concentrations and treatment residence times are summarized in Table IV-19. The coalescing media size was changed in the PressureClear system. Two sizes, defined by the vendor to be 1 inch and 1/2 inch, were tested in the oil-spike tests. The sizes roughly correspond to the spacing between the slant-rib parallel coalescing plates. A small increase in the O&G RE was observed with decreasing spacing. This is as expected; decreasing the spacing between the plates increases the surface area available for coalescence (more plates per inch), thereby increasing the rate of coalescence. However, as the spacing between the plates is reduced, the potential for clogging is increased.

TABLE IV-19. AVERAGE RE AS A FUNCTION OF COALESCING MEDIA SIZE FOR THE VTC-5 PROCESS IN THE OIL-SPIKE TESTS.

Coalescing Media Size[a]	Average RE[b] (%)
1 inch	66
1/2 inch	73

[a]Nominal vendor-specified size.
[b]Over tests at low spiked-oil concentration (177 to 388 mg/L) and long treatment residence times (80 to 90 minutes).

c. Biotreatment of Lagoon Water

As described in Appendix E, a second biotreatment system was set up at the lagoon, and was tested while treating the lagoon water. The system processed lagoon water samples once a day. The average influent concentration was 77 mg/L and the average O&G RE was 56 percent. This relatively low RE is not a measure of the process capability in general but is, instead, more a reflection of the low influent O&G concentration into the system. This average RE is comparable to that measured in the static and dynamic tests on ACWR discharge during Part 1 of the test program. Oil-spike tests were not performed with this system. Figure IV-12 shows,

separately, the average RE performance of the biotreatment process in treating lagoon water during each part of the test program.

d. Membrane Ultrafiltration System Testing

The performance of the polymeric membrane system in treating a number of wastewater streams was tested during Part 1 of the field test program. Figure IV-13 presents the average influent and effluent O&G concentrations for the tests performed, with ranges indicated by the error bars. The average RE was greater than 90 percent (see Table IV-9).

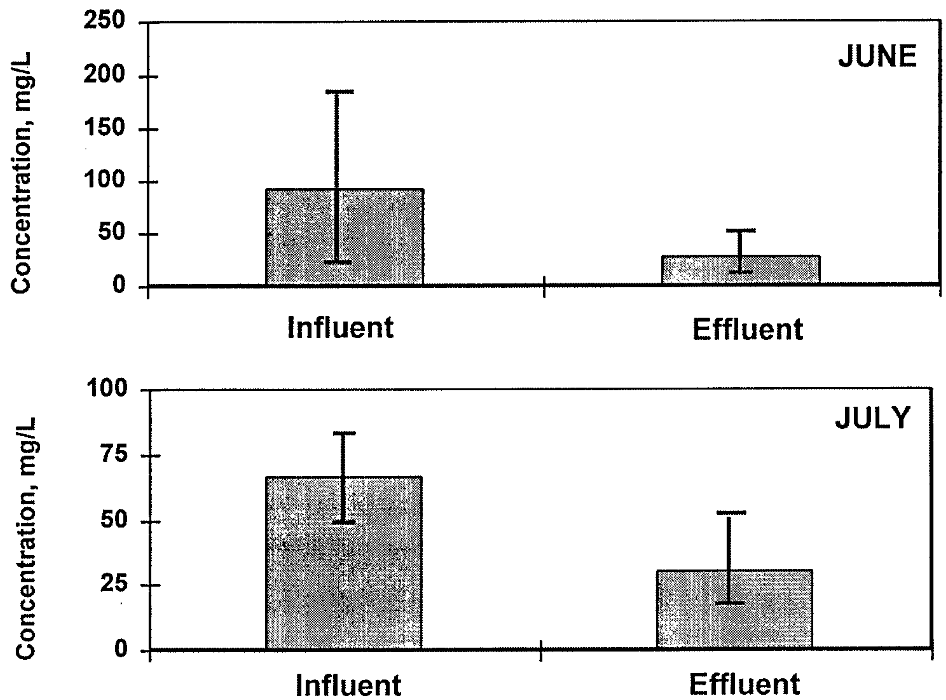

Figure IV-12. Performance of the Biotreatment System in Treating Lagoon Water.

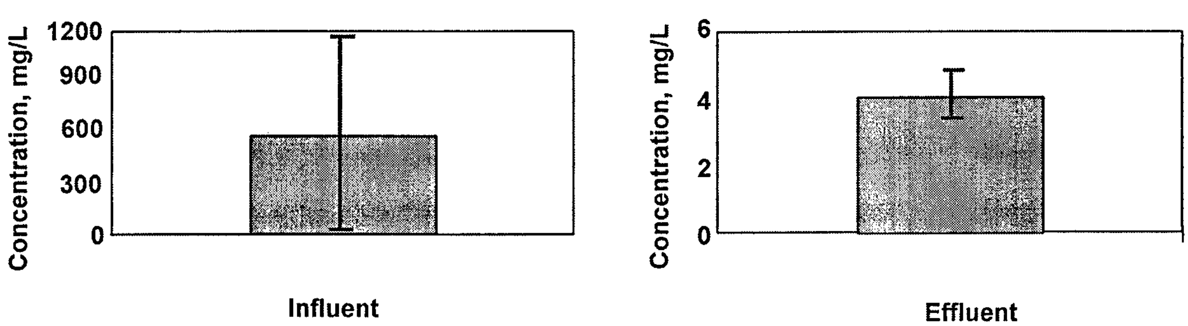

Figure IV-13. Performance of the Membrane Ultrafiltration System.

2. Operations and Maintenance (O&M) Requirements

The actual testing phase of this program comprised a total of 5 weeks. This length of time was not sufficiently long to allow a comprehensive evaluation of the O&M requirements of the various systems. However, sufficient operations experience was gained to allow projecting the performance of the various systems tested from an O&M viewpoint. The projected O&M requirements for each separator technology type are discussed in the following subsections.

a. Coalescing Media Processes

Both of the coalescing media used in these tests were made of polymer materials. As such, they were light and could be easily cut and shaped to fit chambers with different geometries. While substantial concentrations of suspended solids were not encountered in the discharge streams tested in the test program, it was still clear that both coalescing media tested would require periodic cleaning. However, such cleaning of coalescing media should require little effort. This was the experience at the completion of the test program; both coalescing media systems, and the extra PressureClear system media tested, were easily cleaned before being returned to the process vendors. Coalescing media are ideal for retrofit applications, and the only significant additional maintenance requirement is the need for periodic cleaning. The cleaning operation should consist of, at most, hosing the media with water (preferably hot water) and a detergent to remove accumulated O&G and solids. It is expected that if the O/W separator in Building 583 or the one at the lagoon at Dover AFB were retrofitted with coalescing media, preventive maintenance should be required no more frequently than once every 6 months to ensure continued operation at maximum efficiency.

b. Organoclay Filtration

Clay filtration media are designed be used mainly as a secondary treatment. In primary treatment applications, O&M costs are projected to be high due to the requirement that media be replaced frequently. The organoclay medium is non-regenerable; thus, it will require disposal once spent. Disposal costs may be significant, depending on the discharge water contaminants. Certain contaminants may

cause the medium to be designated as a hazardous waste. Based on the test program results, it is estimated that at least 750 lb of organoclay would be required annually for secondary treatment of the Building 583 O/W separator discharge.

The test program did not evaluate the effects of flow rate on the operation of this system. However, the operating flow rate would be an important paramater that will require some level of monitoring and control to maintain optimum removal efficiency.

c. **Biotreatment**

The biotreatment method used in this test program required minimal O&M. The microbes and nutrients are periodically added to an existing separator. In this test program, they were automatically introduced once a day in solution form using peristaltic pumps operated with a timer-switch. Routine maintenance will involve inspecting the pumping system and replenishing the microbe and nutrient solutions. In an actual application, brief bi-weekly preventive maintenance checks should be sufficient.

d. **Chemical Treatment Processes**

Chemical demulsification and flocculation for the treatment of oily wastewater will be highly O&M-intensive. The chemical treatment process requires systems to mix the chemical additives, adjust wastewater pH, and filter the resulting suspended solids. The process also requires significant operator attention. In addition, filtered solids/sludge will require disposal. Data from these tests (see Table IV-15) indicate that the average suspended solids concentration in chemically-treated ACWR discharge will be about 600 mg/L. Thus, for an operation that washes 130 aircraft annually, at 20,000 gallons of washwater per aircraft, about 13,000 lb of floc per year will be generated.

e. **Membrane Separation Systems**

The membrane ultrafiltration system tested in this program was quite simple to use. However, despite being easy to operate, the system will require substantial maintenance effort. It has to be routinely cleaned with specialized detergents and hot water. Furthermore, the polymer membrane is non-regenerable and

will need replacing once it is completely fouled. A system in continuous operation will require continuous operator attention, and membrane cleaning after each wash cycle.

Membranes that process aqueous streams must be maintained in clean and wet condition in order to prevent membrane failure in the form of fouling and drying/cracking. While the membrane clean-up step can be automated, it is a critical step that must be incorporated into the O&M procedures of membrane separation systems.

3. Conclusions and General Recommendations

The following are conclusions and general recommendations with respect to the selection of an O/W separator process for the treatment of wastewater discharges from AF facilities, based on the data and experience acquired and developed in this test program.

- Coalescing media are cost-effective retrofit devices for simple gravity separators. While the ACWR discharge data for the selected equipment do not show a significant increase in the O&G RE with the use of coalescing media for low-concentration discharges, effluent from the systems containing coalescing media contained lower O&G concentrations in general, was clearer, and exhibited less severe fluctuations in treated water O&G levels. Coalescing media require minimal maintenance for efficient operation. Only simple preventive maintenance steps, such as periodic media cleaning to remove solids/sludge from the interstitial spaces, are required for proper operation.
- Biotreatment is another simple and cost-effective retrofit process, best used as an augmentation technology. However, biotreatment processes do require long treatment residence times. These long residence times are needed for both bacterial growth and bacterial destruction of the oily wastewater constituents. Although not evaluated in this test program, biotreatment processes can provide additional benefits such as BTEX, phenol, and other toxic organic constituent removal; and some biological

media have been used to remove toxic trace metals from aqueous streams. An important factor not addressed in this test program is the effect of temperature on biotreatment. Optimal biotreatment temperatures during wastewater treatment are generally between 55°F and 80°F. Temperatures significantly lower or higher than this range may render the system inefficient.

- Depending on the degree of O&G removal from the wastewater required in specific applications, a number of secondary treatment options are available. The three secondary treatment technologies tested in this program (membrane separation, organoclay filtration, and chemical demulsification) were all effective in removing the O&G down to very low concentrations. However, such secondary treatment systems are cost- and/or labor-intensive. Economic benefits from secondary treatment systems may be realized in instances where allowable discharge limits are very stringent, and in cases where wastewater recycling is highly desirable.

G. REFERENCES FOR SECTION IV

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IV-2. Technical Literature and Technology Review for Physiochemical Processes for Oil/Water Emulsion Treatment, Draft Scientific and Technical Report for New Technology for Oil/Water Emulsion Treatment — Phase I, Contract #F08637-95-D6003/D5302, Acurex Environmental Corporation, Mountain View, California, January 1997.

IV-3. Yi, Y., Removal of Oil and AFFF from Wastewater by Air-Sparged Hydrocyclone Technology, Phase I Program Final Report, AFB SBIR Contract F08637-95-C-6014, 1996.

APPENDIX A

THEORY OF EMULSION FORMATION AND BREAKAGE

A. DEFINITION AND TYPES OF EMULSIONS

An emulsion is a mixture of two immiscible liquids, one of which is dispersed in the other in the form of droplets with diameters greater than 0.1 μm.[A-1] Emulsions have long been of practical interest because of their extensive everyday applications. Emulsions are used in foods (milk and mayonnaise), cosmetics (creams and lotions), pharmaceuticals (soluble vitamins and hormone products), agricultural products (insecticides and herbicides), and the petroleum recovery and processing industry.

In petroleum emulsions, one of the liquids is aqueous, and the other oil or grease. Two types of emulsions are commonly encountered, depending on which liquid forms the continuous phase: (1) oil-in-water for oil droplets dispersed in water; and (2) water-in-oil for water droplets dispersed in oil (see Figure A-1). The type of emulsion formed by water and oil depends mainly on the nature of the emulsifying agents present and, to a lesser extent, on the process in which the emulsion is formed and the relative properties of the oil and water present. In all cases, the concentration of the continuous phase must be at least 10% by volume. Because the feeds to AF O/W separators usually contain relatively low levels of O&G in water, the emulsions formed are oil-in-water with oil droplets dispersed in the continuous water phase.

B. EMULSION FORMATION AND STABILITY

The mechanisms controlling the formation and stability of emulsion systems have been subjects of many studies for over a century; however, no comprehensive theory has been developed to explain and predict emulsion formation and stability. The effects of factors such as temperature and pressure and the roles of emulsifiers and stabilizers on these systems are not fully understood.

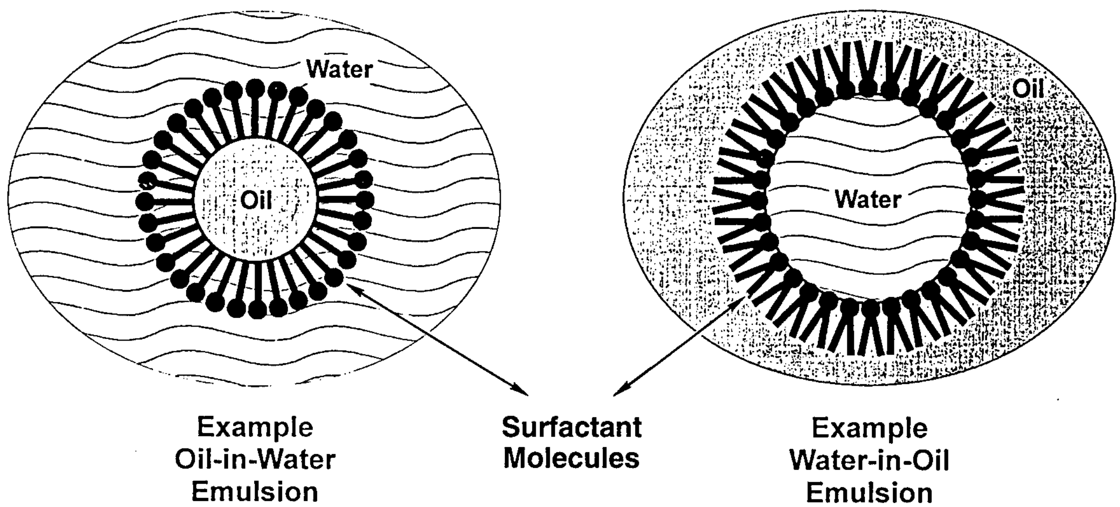


Figure A-1. Schematic Illustration of Oil-in-Water and Water-in-Oil Emulsions.

1. Formation of Emulsions

In the formation of an emulsion, one of the immiscible liquids is broken up into droplets and dispersed in the other liquid. This process produces a large increase in the interfacial area between the two liquid phases, resulting in a correspondingly large increase in the interfacial free energy of the system. Therefore, an emulsion system is thermodynamically unstable. To form a stable emulsion, a third component, such as an emulsifier or a stabilizer must be present to stabilize the system. The emulsifier or the stabilizer adsorbs at the liquid-liquid interface, forming an interfacial film, which: (1) lowers the interfacial tension between the two liquids thereby reducing the energy required for droplet formation; and (2) retards the coalescence of droplets by forming mechanical, steric, and/or electrical barriers around them. Emulsifiers and stabilizers usually comprise one or more of the following: simple inorganic salts; fine particles; polymers; and surfactants as illustrated in Figure A-2.[A-2]

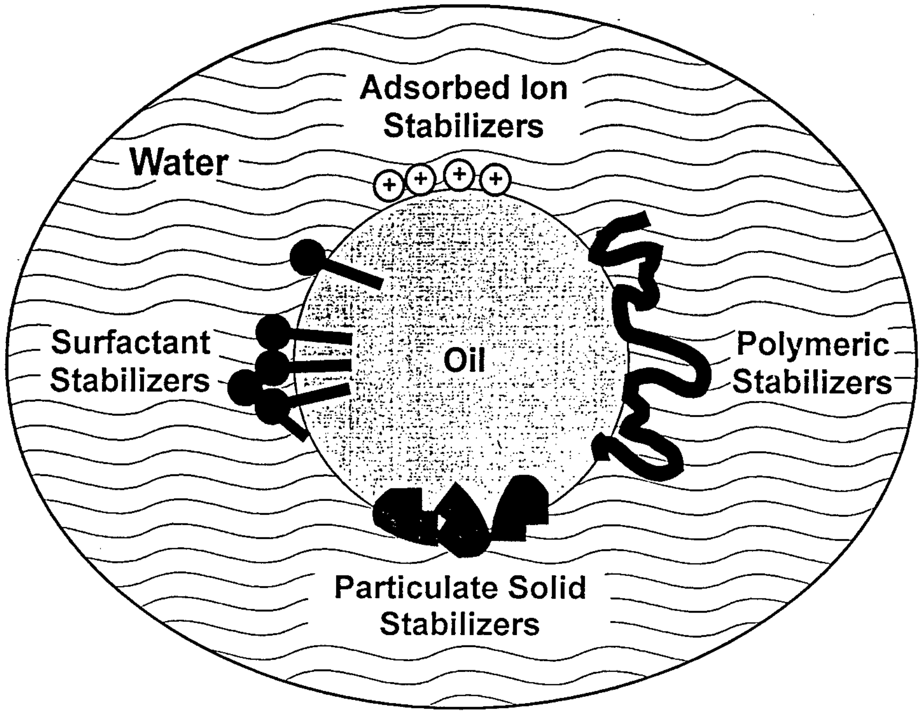
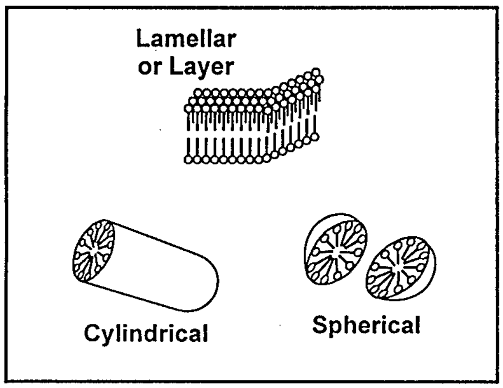
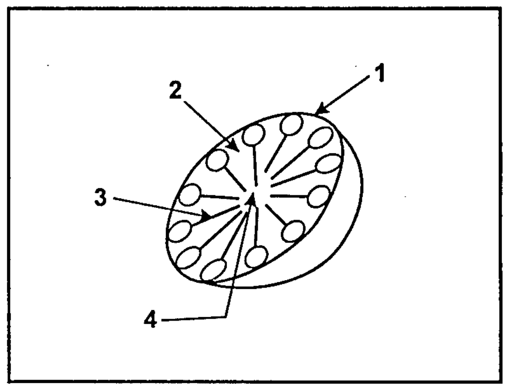


Figure A-2. Mechanisms of Emulsion Stabilization.

Surfactants are the most common and effective emulsifiers or stabilizers. Emulsions occurring in the AF O/W separators are most likely caused by the presence of surfactants, detergents, and soaps in the washwater from various washing operations. In general, a surfactant molecule has one polar, water-soluble (hydrophilic) end, and one nonpolar, oil-soluble (oleophilic or lipophilic) end. The polar end usually carries either a negative (anionic) or positive (cationic) charge, but can be electrically neutral (nonionic). The nonpolar end usually consists of a long lipophilic chain. When the concentration of a surfactant increases, an aggregate of surfactant molecules will form a large organized structure called a micelle in which the lipophilic ends of the surfactant molecules turn inward, leaving the hydrophilic ends to face the aqueous medium. The micelles may be present in layered (or lamellar), cylindrical, or spherical forms, and can solubilize oil and grease as illustrated in Figure A-3. Surfactants also will migrate to the O/W interface, providing an expanding force acting against the

normal interfacial tension. In this way, surfactants lower the interfacial tension and facilitate emulsification. Anionic or cationic surfactants stabilize emulsions even further by forming a consistent charged layer on the oil droplet surface. These charged droplets repulse neighboring droplets with the same electrical charge and inhibit the ability of the oil to coalesce.





Surfactant Micelle Formations

Possible Areas for Solubilization of Oil on/in a Surfactant Micelle

1. At the micelle/water interface
2. Between hydrophilic groups
3. In the palisade layer, between the hydrophilic and hydrophobic group
4. The inner core of the micelle

Figure A-3. Micelle Formation for Oil/Water Solubilization.

Polymers aid in both emulsion formation and stabilization through steric or electrostatic interactions, changes in the interfacial viscosity, and/or changes in the bulk viscosity of the system.

Fine particles, while not affecting interfacial tensions, can stabilize an emulsion by adsorbing at the O/W interface which imposes a physical barrier between droplets. The dispersed droplets do not readily coalesce because of the interference or blocking effect caused by solids.

Simple inorganic salts will not significantly affect the interfacial tension. Instead, they may aid in stabilizing an emulsion system by imposing a slight

electrostatic barrier between approaching droplets. Alternatively, they may affect the stability of the system by reorienting water molecules in the interface, thereby altering some local physical properties, such as dielectric constant, viscosity, density, etc. These physical properties directly affect the coalescence of droplets.

2. Stability of Emulsions

The factors leading to stable emulsion formation are typical in AF washing operations. For example, in equipment washing, the aqueous-phase is brought into contact with an oil and grease phase on the equipment under the high-shear conditions of a sprayer. This will disperse the oil and grease into the aqueous phase. The surfactants present in the cleaning agents will act as emulsifiers to help stabilize the dispersed phase, leading to the formation of stable and difficult-to-separate emulsions.

Most emulsions are not thermodynamically stable. Instead, they are kinetically stable for a long period of time. Rosen defines emulsion stability as "the resistance of emulsions to the coalescence of their dispersed droplets."[A-3] The oil droplets in an emulsion may undergo the following transformations depending on the stability characteristics of the emulsion:[A-2]

The ***breaking*** of an emulsion (Figure A-4 [a]) refers to a gross separation of the two phases. The stability of the emulsion is completely lost during this process because the physical and chemical properties of the emulsion are lost.

Coalescence refers to the joining of two or more drops to form a single droplet of greater volume, but smaller interfacial area (Figure A-4 [b]) which results in a decrease in the free energy of the emulsion system. The rate of coalescence of droplets in an emulsion is the only quantitative measure of emulsion stability.[A-4]

Flocculation refers to the mutual attachment of individual emulsion droplets to form flocs (Figure A-4 [c]). Although a form of instability, flocculation is not considered as serious a sign of instability as coalescence or breaking of the emulsion.

Creaming refers to the mere rising or settling of the droplets because of density differences between the two phases (Figure A-4 [d]). Creaming occurs over time with almost all emulsion systems, and the rate of creaming depends on the

physical characteristics of the emulsion system, especially the viscosity of the continuous phase and the droplet size of the dispersed phase.

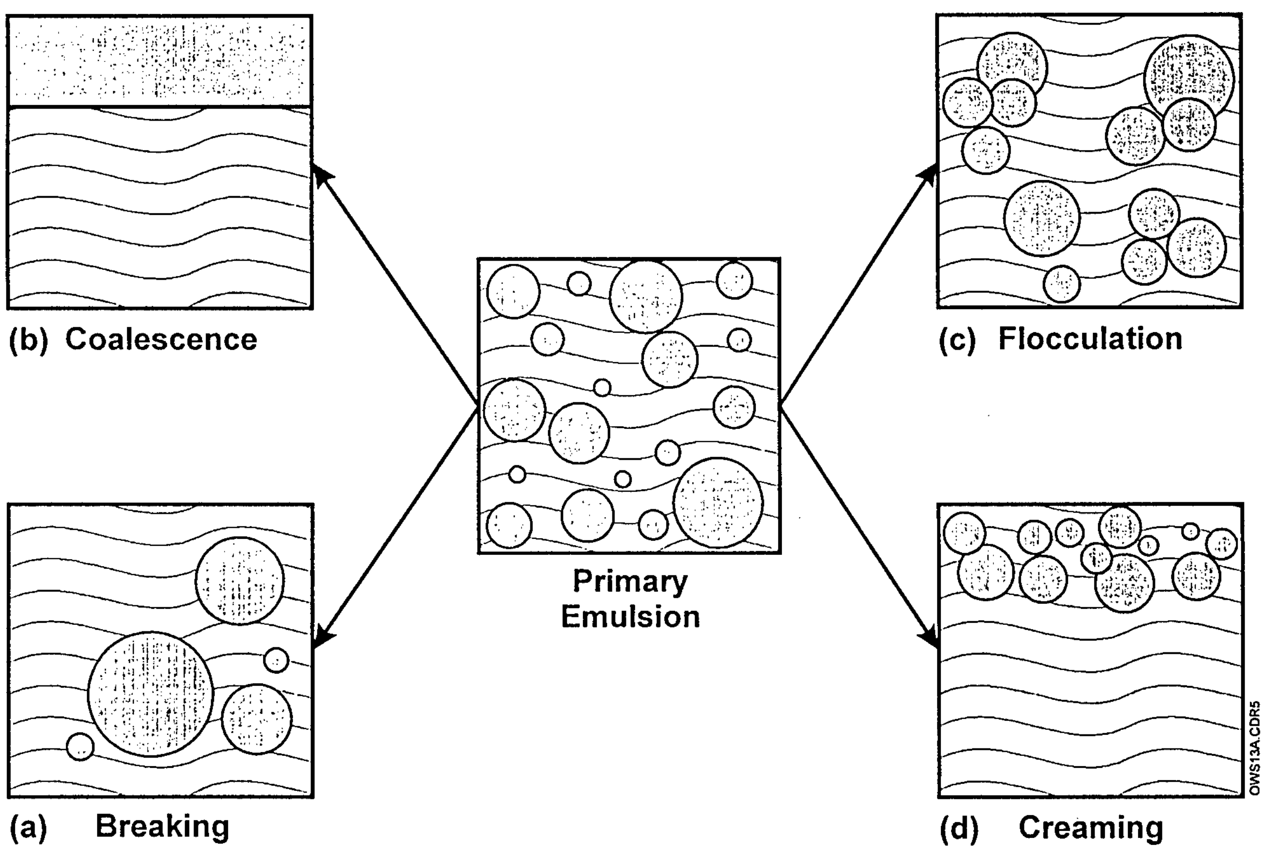


Figure A-4. Emulsion Transformations Over Time.

C. EMULSION BREAKING

Breaking an emulsion requires removing or destabilizing the particulate, charge, and/or chemical agent film on the surfaces of the oil droplets. Once the stabilizing mechanism is removed, the droplets will coalesce and become large enough to be separated from the water phase by gravitational methods. In order to break an emulsion, one must understand the characteristics of the emulsion in terms of its type (oil-in-water or water-in-oil), the nature of the two phases, and the emulsifiers. On the basis of such evaluations, a chemical addition could be made to neutralize the effect of the emulsifier, followed by mechanical means of completing the phase separation.

The addition of chemicals (see examples in Table A-1) can eliminate or neutralize the effects of emulsifying agents to allow the emulsified droplets to coalesce. For example, the accumulated electrical charges on the emulsified droplets can be neutralized by introducing a charge opposite to that of the droplets (see Figure A-5). Chemical emulsion breakers can provide this opposite charge. The emulsified oil-in-water droplets usually carry negative charges. Therefore, a cationic (positive charge) emulsion breaker should be used to destabilize an oil-in-water emulsion. The chemical methods are often combined with other methods to enhance the treatment performance. Destabilizing emulsions can be assisted by the following methods:

1. ***Mechanical methods***: Low shear fields can lead to collisions between oil droplets which may result in coalescence, without breaking down larger oil droplets.
2. ***Thermal methods***: An increase in temperature can decrease the solubility of oils and destabilize an emulsion.
3. ***Electrical methods***: An applied electric field can disturb the surface tension of the droplets and change orientations of polar molecules at the surface. This reorientation weakens the film around each droplet. Moreover, droplets with opposite charges are electrostatically attracted to each other. Both effects lead to coalescence.

TABLE A-1. TYPES OF EMULSION BREAKERS.

Type	Description	Charge
Inorganic	Polyvalent metal salts such as alum, $AlCl_3$, $FeCl_3$, and $Fe_2(SO_4)_3$	Cationic
	Mineral acids such as H_2SO_4, HCl, and HNO_3	Cationic
	Adsorbents (adding solids) — pulverized clay, lime	None
Organic	Polyamines, polyacrylates, and their substituted copolymers	Cationic
	Alkyl-substituted benzene sulfonic acids and their salts	Anionic
	Alkyl phenolic resins, substituted polyalcohols	Nonionic

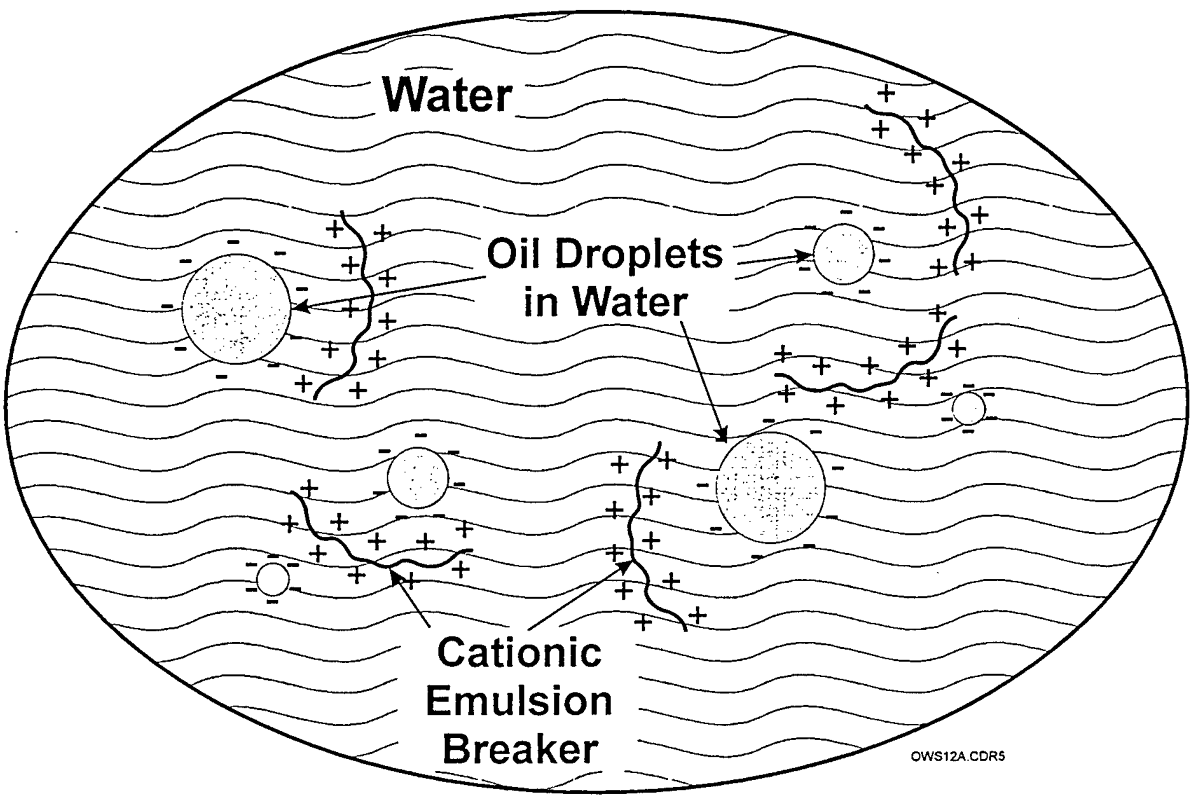


Figure A-5. Application of a Cationic Emulsion Breaker to Neutralize Surface Charges on an Oil Droplet.

D. TREATMENT OF OIL/WATER EMULSIONS

A dispersion of oil in water can be classified into one of three categories:

1. ***Suspended Free Oil.*** The oil either forms a separate layer or large drops on the surface or below the water phase, depending on its specific gravity. The droplet of free oil is usually greater than 100 μm in diameter, and it coalesces easily. Therefore, it is relatively easy to separate free oil from water. Separation can be accomplished mechanically by gravity and contact coalescence.
2. ***Mechanically Emulsified Oil.*** The oil phase may be broken up into small droplets when the O/W mixture is agitated and subjected to high shear forces. The droplet size usually ranges between 2 and 100 μm, and the stability is higher than that of free oil. Larger holding basins, elevated temperature, and contact coalescence (with the aid of coalescer) can effectively remove the emulsified oil.
3. ***Chemically Emulsified Oil.*** In the presence of surfactants or fine particles, a layer of the emulsified molecules will be formed at the O/W interface when the oil phase is broken into droplets. The droplet size is usually between 1 and 100 μm, and the stability is greatly increased as a result of the reduced interfacial tension due to the presence of surfactants. The separation of this type of emulsion is quite difficult, and chemical demulsification is usually needed to break the emulsion.

Nearly all O/W mixtures have some amount of these three types of oil present. The performance of any separation device will depend on the composition and state of the O/W mixtures to be separated. A basic principle behind the separation of a mixture of two immiscible fluids is given by Stokes Law:

$$u = \frac{(\rho_d - \rho_c) d^2 g}{18\mu} \tag{A-1}$$

Where:

u	=	Settling velocity (a negative velocity indicates that the dispersed phase is rising)
ρ_d	=	Density of the dispersed phase (oil)
ρ_c	=	Density of the continuous phase (water)
d	=	Dispersed phase droplet diameter
g	=	Gravitational acceleration
μ	=	Dynamic viscosity of the continuous phase (water)

To facilitate the separation process, the upward velocity must be maximized; the travel distance necessary for separation must be reduced; and/or the time available for separation must be increased. This can be achieved by:

1. Increase the density difference $(\rho_d - \rho_c)$. This can be done by attaching the oil droplet with fine air bubbles which act as buoys. This separation technique is known as flotation.
2. Increase the oil droplet diameter *(d)*. This is a very effective method because the differential velocity increases as the square of the diameter. Increasing droplet diameter also decreases the separation distance between droplets. This method is employed in the technique of coalescence where many small droplets join together to form one large drop. Coalescence also may be aided with chemical additives.
3. Increase the gravitational acceleration. In centrifugal separation, this term is replaced by a centrifugal acceleration of much greater intensity.
4. Decrease the viscosity of the continuous phase (water) by increasing the temperature, for example.
5. Increase the residence time. This allows the smaller oil droplets to move a greater distance, increasing the probability of the emulsified droplets to coalesce, thus enhancing separation.
6. Increase the surface area-to-volume ratio of the separator. This reduces the distance the oil droplets must travel to be separated.

Separating the emulsified oil is usually considered more of an art than a science because many variables control the stability of the emulsion. Most research has focused on the practical aspects of achieving a separation under specific conditions, but little theory can be extrapolated and applied to practical problems. Practical experience is vital to an effective and economic solution for treating O/W emulsion problems. The techniques discussed above will be used in the separators described in the next section.

E. REFERENCES FOR APPENDIX A

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A-2. Myers, D., Surfaces, Interfaces, and Colloids: Principles and Applications, VCH, New York, New York, 1990, p. 229.

A-3. Rosen, M. J., Surfactants and Interfacial Phenomena, 2nd ed., Wiley, New York, New York, 1989, pp. 305-336.

A-4. Boyd, J., C. Parkinson, and P. J. Sherman, Colloid Interface Sci., 41:359, 1972.

APPENDIX B

BASE NEEDS SURVEY

A. BASE SELECTION PROCEDURE

A selection procedure was developed to select representative AF bases and activities for a base needs survey. The procedure's steps, shown in Figure B-1, are:

- Identify candidate bases that have had compliance or other problems with their O/W separator effluent streams
- Perform telephone interviews with the environmental compliance and civil engineering personnel on each base
- Document and submit the survey information to each base for review and concurrence
- Formulate a preliminary list of survey candidates. Submit the list to the Project Officer for final selection.
- Use the final list to select representative bases/separators having operating problems. Select the widest range of problem types and waste-generating processes using the smallest number of bases.
- Perform detailed telephone interviews with base personnel concerning specific separators and processes that generate wastewater
- Visit the selected bases to confirm/clarify information obtained and to execute onsite sampling

Because only a few NOVs were reported by the bases interviewed, the base selection procedure was modified to de-emphasize the issue of NOVs.

1. Preliminary Survey

A preliminary list of 21 AF installations (see Table B-1) was created by collecting information from various sources, including the project officer, major AF Commands, and reports prepared by International Technology (IT) Corporation[B-1] and Sverdrup Environmental, Inc.[B-2] for the AF. Telephone interviews were performed with environmental compliance and civil engineering (CE) personnel at each base. The questions asked were grouped into several categories:

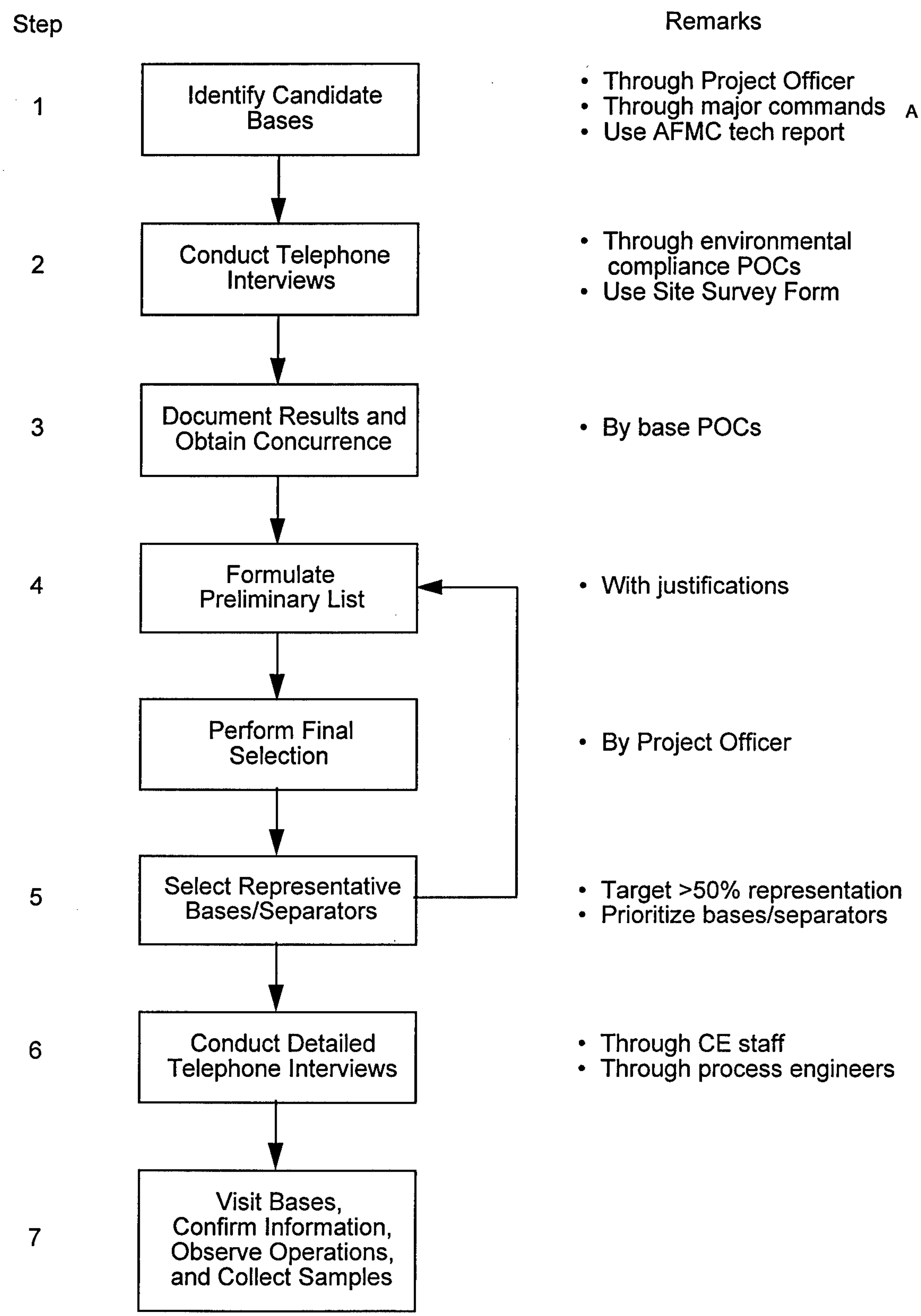

Figure B-1. Base Selection Procedure.

Base Contacted			Primary POC			Secondary POC			Existing Separ			
Base	State	Command	Name	Office and Position	Telephone No.	Name	Office and Position	Telephone No.	Number	Types	Age	Processes Feeding S
Barksdale	LA	ACC	Paul Hughes	Chief of Compliance; 2nd CES/CEV	(318) 456-3541	Johnny Smith	Manager, CEOW shop	(318) 456-8919, or 8727	36	Sverdrup has a complete listing, most are concrete gravity separators	See Sverdrup data.	See Sverdrup data. B-5 most concern
Brooks	TX	AFMC	Andrew Rielly	Environmental Management	(210) 536-6702	NA	NA	NA	3	Gravity separators	Unknown	Car wash and vehicle m area.
Cannon	NM	ACC	Gene Smith	Environmental Engineer; 27th CES/CEV	(505) 784-4639	John Rebman	NA	(505) 784-2739	48	44 Gravity type, a mix of steel and concrete. Approx. 3 coalescing devices, the others are baffled chambers. Only 23 are currently operational. 4 close-loop pretreatment systems (centrifuge, filters, and chemical addition.)	A mix of old and new separators. The oldest is 45 years old.	Aircraft (F-16s) washing washing, bulk fuel spill area. The closed-loop sy service 3 vehicle and 1 a washracks.
Charleston	SC	AMC	Bill Deane	NA	(803) 566-4975	Jeff Garrett	Water, wastewater, and underground storage tank (UST) Manager; Environmental Management	(803) 566-2699	22	Most are concrete cells with concrete baffles. Some have skimmers. Newer separators are steel tanks, and may have coalescing media	NA	Aircraft and equipment engine test cells, and so shop drains
Davis-Montham	AZ	ACC	John Maisch	Compliance Engineer; 355th CES/CEV	(520) 228-4774	NA	NA	NA	45-50	Most are baffled concrete chambers. 2 tanks with coalescing devices	Coalescing types are ~6 years old Baffled chambers are older	Aircraft, vehicle, and eq washracks. AMARC fa aircraft so a wide variety are washed. Aircraft are aggressively cleaned wi cleaners
Dover	DE	AMC	Steve Seip	Environmental Management	(302) 677-6843	NA	NA	NA	24	Most are just gravity separators, 4 have coalescing plates	Some new, but most are 50-60 years old.	Vehicle and aircraft was fuel cell, engine fuel cell around fuel area
Edwards	CA	AFMC	Don Cowan	IRP Group	(805) 277-1439	NA	NA	NA	90	Some have filters after the separators	A mix of old and new separators. The oldest is 45 years old.	Hangars, washracks, an
Eglin	FL	AFMC	Larry Chavers	Compliance	NA	NA	NA	NA	55	Several, beginning with basic weir types.	Many old separators.	NA
Grissom	IN	AFRES	Jeff Woodring	Chief, Environmental Flight	(317) 688-4561	NA	NA	NA	23	Baffled chambers. No coalescers currently in use. A pretreatment system for a washrack was used in the past. Large washracks now go to a sequential batch reactor.	5-30 years old.	Aircraft (KC-135Rs) an washracks. Maintenan
Langley	VA	ACC	Vern Bartells	Environmental Management	(804) 764-3506	Bernie Kruse	CE	(804) 764-2031	25	Mixture of old and new gravity separators with skimmers and weirs.	Most are 40-50 years old.	Vehicle maintenance, h hangars, and hush hous
Luke	AZ	ACC	Brian Biesemeyer	CES/CEV	(602) 856-3621	Caye Thomas	NA	(602) 856-3621	71, (~10 are inactive)	All are concrete or metal chambers with baffles. A few of the aboveground separators have coalescing plates	1963-present.	Aircraft and vehicle wa washdown areas, and a impoundment area. Th wastestreams include s detergents, solvents, an products.
Martinsburg	WV	ANG	Col. Burkhart	NA	(304) 267-5233	NA	NA	NA	NA	NA	NA	NA
McChord	WA	AMC	Tom Lee	Water and Wastewater Project Manager	(206) 984-3913	Chan Smith	NA	(206) 984-3913	65	Most are 3-chambered baffled tanks. Some have coalescing plates, but are suspected to work inefficiently	NA	Aircraft and vehicle wa racks, and shop floor d
Mountain Home	ID	ACC	Stephanie Bingelli	Water Quality Manager, CES/CEV	(208) 828-4247	Gary Burton	Chief, Environmental Flight	(208) 828-6391	54	Flow-through gravity separation chambers with baffles, centrifugal mechanical separators, and RGF treatment system	Most are very old	Aircraft (wide range be base is a composite wi vehicle washracks, floo storage areas, and corro
Nellis	NV	ACC	Dan Shickler	Compliance Engineer	(702) 652-2072	NA	NA	NA	45	Baffled concrete chambers	Most are about 20 years old	Aircraft (F-16s, F15s, A helicopters), vehicle, an washracks. Maintenan

TABLE B-1. PRELIMINARY I

	Existing Separator Information				Performance Monitoring					
					Discharge Limits					
	Processes Feeding Separators	Discharge Receiver	Current Problems	Recognition of Emulsion Problem	O&G (mg/L)	TPH (mg/L)	Sampling Frequency	NOVs	Improvement Plans	Add
up	See Sverdrup data. B-52 area of most concern.	All but one are sent to a POTW.	At B-52 washing area, storm water also enters the separator.	Not investigated, but likely.	100	NA	Sampling performed during annual separator cleaning CEOW responsible for daily inspection of O/W separators.	No	Current project designed by AFCEE to remove 11 separators by installing closed-loop washracks on maintenance activities	Base POC v information upon reque
	Car wash and vehicle maintenance area.	Sanitary sewer to POTW.	Periodic cleanout.	Not mentioned	200	NA	Once per year.	No	Only repair and maintenance as needed	NA
ld is l.	Aircraft (F-16s) washing, vehicle washing, bulk fuel spill containment area. The closed-loop systems service 3 vehicle and 1 aircraft washracks.	On-base treatment lagoons discharge to a playa.	None mentioned.	Not mentioned.	100 (listed in IT report, Base POC unaware of limit.)	NA	Performed annually by a contracted lab. Analysis for O&G not included with TPH.	No	Finishing a pretreatment design project that will add 2 more closed-loop systems. 2 separators will be removed to examine surrounding soil for SWMU determination. Some separators will be replaced.	POC has be only non-en has instruct discharge to discontinue detergents, f find an alter solution
	Aircraft and equipment washing, engine test cells, and some industrial shop drains.	North Charleston Sewer District.	Washing of C-17s and C-141s have caused cadmium and maintenance problems. Currently, a contractor monitors the separators. User education.	Has not looked into this topic. One base POC felt that the high O&G was not from TPH. TPH was only 1/5 of the O&G.	300 daily; 200 monthly, previously 150 and 100.	150 daily; 100 monthly	Sampled only during maintenance of the separators	Yes, NOV for O&G However, no TPH, O&G traced to food wastes	O&G limits have been increased. User education.	There was a receiving th to fund a la that will do wastewater base. This funded or a
·) re	Aircraft, vehicle, and equipment washracks. AMARC facility stores aircraft so a wide variety of aircraft are washed. Aircraft are aggressively cleaned with HC-based cleaners	Roger Road POTW.	High metals (Cd, Pb, Zn, and Cu in this order) from the aggressive cleaning at the main wash rack.	Base POC expects O&G problems, but the highest O&G analysis recorded was 9 ppm	200	NA	Once per month for O&G, TPH, and BTEX. Quarterly for additional analytes Sampling is performed at AMARC, Hospital, and Flight Line	No	Pretreatment system for main wash rack with dissolved air flotation, ion exchange, sludge press, equalization tank, and traditional separator. Will also review recommendations of recent Sverdrup and Parsons studies	Sverdrup an investigated report is in. Parsons rep includes 10
but l- l.	Vehicle and aircraft washracks, test fuel cell, engine fuel cell, and dikes around fuel area.	15 to Kent County POTW, 9 to storm sewer.	Maintenance, inefficient design.	NA	360	NA	Once per month from outlet of discharge line.	No	Replacing 3 separators	Have had d O&G. IT C separators t
d is l.	Hangars, washracks, and labs.	On-base sewage treatment plant (not an IWTP).	Maintainability and service. Silty soil used to blind filters.	In past, but not currently.	None	None	For unit functionality, ~once per month.	No	Studying operation and maintenance. Phasing out old units	Hope to red 45 to 60. N ground
	NA	On-base sewage treatment plant (not an IWTP). Processes not discharged to the base treatment plant are collected in large tanks.	Maintenance, access to units and confined space issues.	Not mentioned.	NA	NA	NA	No	Removing some separators and upgrading diverter valves on washracks to prevent stormwater runoff from entering separators	Interested i
old.	Aircraft (KC-135Rs) and vehicle washracks. Maintenance facilities.	Most separators are discharged to base wastewater treatment plant. Some directly discharged to storm sewer.	None mentioned.	Not mentioned	None	NA	Monthly checks for oil levels, but no other sampling	No	None	NA
)- l.	Vehicle maintenance, hobby shop, hangars, and hush house	Hampton Road POTW.	Old and undersized separators.	Yes	50	10 (potential)	Done at final lift station before discharge to POTW, weekly	Yes	Replacement process is ongoing. Working on better maintenance and education of users	Have mone separators t
nt.	Aircraft and vehicle washracks, washdown areas, and a POL impoundment area. The wastestreams include surfactants, detergents, solvents, and paint products.	Most discharge to base wastewater treatment plant. A few discharge to storm sewer.	Poor management and maintenance. High phenol discharges in excess of permit.	Base POC suspects a problem, especially at the transportation wash rack.	None	NA	Usually they don't sample the separators, but at most once per year.	No	Working in-house on a separator management plan to decide which to replace or remove from the system. Phenols problem solved by feeding microbes into the influent line. Project has been successful	Base POC participatin expressed a innovative contractor survey, but do it better
	NA	NA	NA	NA	NA	NA	NA	Yes, for surfactants	Decrease amount of detergent used	NA
	Aircraft and vehicle washracks, paint racks, and shop floor drains.	Base POC suspects that only 1 separator discharges to Fort Lewis POTW, 5 separators discharge to storm sewer, and remaining separators have no discharge.	Sludges, inefficient skimmer operation, and stormwater runoff.	Not mentioned	100 POTW, 15 to storm sewer	NA	Quarterly for those that are in the NPDES permit.	No	Base POC unaware of any.	Additional
ry	Aircraft (wide range because the base is a composite wing) and vehicle washracks, floor drains, fuel storage areas, and corrosion control.	Most discharge to a lagoon treatment system. All industrial wastewater will be routed to new IWTP in 1997. Storm water is discharged to a delineated wetland.	Emulsions present in discharge. Many of the separators are in poor condition and need maintenance.	Base is concerned with emulsions from washracks, any place with jet fuel, and from corrosion control	None. New treatment plant will have NPDES permit	NA	None until last year. Did some sampling when most of the separators were cleaned last year	No	Base POC set a goal of removing majority of the separators. They will be rerouted or replaced with pretreatment systems (including aboveground mechanical separators) Several ongoing projects in this area	Base POC a big probl proactive n She is very technologi
nout .l	Aircraft (F-16s, F15s, A-10s, and helicopters), vehicle, and equipment washracks. Maintenance activities	All discharge to Clark County Sanitation District POTW.	Age of equipment and corrosion in pipe infrastructure	Detergents do enter the separators, but Mr Shickler said that no oily discharge has been noticed	400 (from IT report)	NA	Annually. Done by base personnel. Analyze for VOCs and metals only	No	Looking into replacing less efficient separators Five will be replaced	NA

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TABLE B-1. PRELIMINARY BASE LIST.

NOVs	Improvement Plans	Additional Comments
No	Current project designed by AFCEE to remove 11 separators by installing closed-loop washracks on maintenance activities.	Base POC will provide additional information from Sverdrup report upon request.
No	Only repair and maintenance as needed.	NA
No	Finishing a pretreatment design project that will add 2 more closed-loop systems. 2 separators will be removed to examine surrounding soil for SWMU determination. Some separators will be replaced.	POC has been told by HQACC to use only non-emulsifying detergents. He has instructed base users who discharge to an O/W separator to discontinue use of emulsifying detergents, but has not been able to find an alternative cleaning method or solution.
:s, NOV r O&G wever, no H, O&G aced to d wastes	O&G limits have been increased. User education.	There was no negative impact from receiving the NOVs. They are hoping to fund a large contract for a survey that will do a comprehensive wastewater characterization for the base. This contract has not yet been funded or awarded.
No	Pretreatment system for main wash rack with dissolved air flotation, ion exchange, sludge press, equalization tank, and traditional separator. Will also review recommendations of recent Sverdrup and Parsons studies.	Sverdrup and Parsons have both investigated the separators. Sverdrup report is in, but still waiting for Parsons report. Parsons report includes 10% design phase.
No	Replacing 3 separators	Have had discharges with 50 mg/L O&G. IT Corp. sampled some of the separators in 1996.
No	Studying operation and maintenance. Phasing out old units.	Hope to reduce operating separators to 45 to 60. New units are above ground.
No	Removing some separators and upgrading diverter valves on washracks to prevent stormwater runoff from entering separators.	Interested in close-looping washracks.
No	None	NA
Yes	Replacement process is ongoing. Working on better maintenance and education of users.	Have money to replace 2 to 3 separators in FY97.
No	Working in-house on a separator management plan to decide which to replace or remove from the system. Phenols problem solved by feeding microbes into the influent line. Project has been successful.	Base POC was enthusiastic about participating in the study, and expressed an interest in new and innovative projects. AETC has a contractor performing a wastewater survey, but Luke felt that they could do it better on their own.
es, for factants	Decrease amount of detergent used.	NA
No	Base POC unaware of any	Additional information is needed.
No	Base POC set a goal of removing majority of the separators. They will be rerouted or replaced with pretreatment systems (including aboveground mechanical separators). Several ongoing projects in this area.	Base POC feels that O/W separation is a big problem. She is trying to be proactive in addressing the problem. She is very interested in new technologies and systems.
No	Looking into replacing less efficient separators. Five will be replaced.	NA

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Base Contacted			Primary POC			Secondary POC			Existing Separat			
Base	State	Command	Name	Office and Position	Telephone No.	Name	Office and Position	Telephone No.	Number	Types	Age	Processes Feeding Se
Patrick	FL	AFSPC	Wayne Neville	Recycling Coordinator	(407) 494-9268	Joan Albury	NA	(407) 494-2899	12	Most are baffled concrete chambers. At least one has coalescing plates.	Most are old	Aircraft (C-130s, helicopt some others) washrack, ca facilities, auto hobby shop maintenance shop, fuel fa and waste oil and spillage
Reese	TX	AETC	Chris Morris	Environmental Restoration	(806) 885-6252	NA	NA	NA	6; 2 inactive	Most are concrete chambers with concrete baffles. New separator is an aboveground steel tank (unaware of any coalescing media).	Most are old. 1 installed approx. 1 year ago.	Primarily vehicle and airc washing
Seymour-Johnson	NC	ACC	Dean Chastain	Water Quality Program Manager; 4th CES/CEV	(919) 736-6690	Bryan Henderson	NA	(919) 736-6690	45	Most are baffled concrete chambers. Some have parallel plate separators	A range from about 30 years to 1 month	Aircraft (F-15s and KC-1 vehicle washing, and mai shops. Base POC suspect detergent used in many p simple green
Travis	CA	AMC	Dave Musselwhite	Environmental Management, Environmental Engineer	(707) 424-3885	Gisiok Thang	Environmental Management, Director	(707) 424-3587	24	NA	NA	Washracks, maintenance and diked fuel tank areas
Tyndall	FL	AETC	Jon Davis	Environmental Engineer, Environmental Flight; Civil Engineering	(904) 283-2493	Mike Jones	Environmental Management	(904) 283-4346	21	Most are concrete chambers. Three new ones are steel tanks with coalescers. 4 or 5 are just tanks that maintain a level.	Between 1-30 years. Most are probably newer	Vehicle and aircraft wash washing of shops, engine facilities (3), fuel storage shop, and pumped bilge v
Wright-Patterson	OH	AFMC	Lilly True	Environmental Management, Wastewater Program Manager	(513) 257-5535 ext. 251	Tony Sculimdrene	Environmental Management Officer	(513) 257-5627	68	Most are gravity concrete chambers. 4 new ones have just been installed.	Most are very old.	Vehicle and aircraft wash hangar drainage, hobby s outdoor drainage areas, a facilities

AFCEE=Air Force Center for Environmental Excellence; IWTP=Industrial Wastewater Treatment Plant; NA=Not Available; NOVs=Notice of Violation; O&G=Oil and Grease; POC=Point of Contact; POL=Petroleu
POTW=Public-Owned Treatment Works; SWMU=Solid Waste Management Unit; TPH=Total Petroleum Hydrocarbons

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TABLE B-1. PRELIMINA
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Existing Separator Information					Performance Monitoring						
					Discharge Limits						
Age	Processes Feeding Separators	Discharge Receiver	Current Problems	Recognition of Emulsion Problem	O&G (mg/L)	TPH (mg/L)	Sampling Frequency	NOVs	Improvement Plans		
›st are old.	Aircraft (C-130s, helicopters, and some others) washrack, car wash facilities, auto hobby shop, vehicle maintenance shop, fuel farm area, and waste oil and spillage area	Cocoa Beach POTW. Three discharge to storm sewer.	Suspects that separators that service the fuel storage area may be undersized.	None suspected.	50	NA	No regular sampling.	No	Replacement of separator at the auto hobby shop.		Pat con Sta Car
›st are old, ›stalled ›rox. 1 year	Primarily vehicle and aircraft washing	2 into a basic treatment plant and then discharge to a playa. Others discharge directly to the playa.	Inappropriate wastes entering the separators. The NOV problem has been remedied by educating the users to wipe down exhausts before washing. Problems with the pumps	None noticed.	None, but TSS=15 mg/L.	None	At least annually, and before disposing of sludge.	Yes, but not for O&G. Most recent NOV is from March. NOVs for TSS, Cd, and Cr.	Education of users.		Bas
›ange from ›ut 30 years ›t month.	Aircraft (F-15s and KC-135s), vehicle washing, and maintenance shops. Base POC suspects that the detergent used in many processes is simple green.	All discharge to Goldsboro wastewater treatment facility.	NA	Not mentioned	100	NA	No regular sampling is performed, except at final lift station. Parsons conducted a pretreatment study early in 1996 and sampled all of the separators. Armstrong Laboratory sampled sludge and floating layers in 1995.	No	3 washracks will be replaced with new separators. Base had considered closed-looped treatment system, but found that it was not economical because their sanitary costs are very low.		NA
›	Washracks, maintenance floor drains, and diked fuel tank areas.	19 to Fairfield Suisun Sewer District, 5 to storm sewer.	Inadequate design, undersized separators	No	NA	NA	Frequency unknown, but the effluent is monitored.	No	Some will be modified for waste upgrading		NA
›ween 1-30 ›rs. Most probably ›ver	Vehicle and aircraft washracks, floor washing of shops, engine test facilities (3), fuel storage area, hobby shop, and pumped bilge water.	All are sent to a sanitary line They have their own secondary treatment facility and then to a Bay County managed lagoon, and ultimately to St. Andrews Bay	Undersized, previously not properly maintained, inappropriate waste streams dumped to them. Lack of information (e.g. drawings) of existing separators.	Hasn't noticed any, but separators have appeared soapy, and that these separators contained oil and soap at the same time.	NA	NA	Sampling is done annually, but they do not analyze for O&G.	No	They will soon be feeding into a county treatment works and will replace 9 separators before that time		AF Co sep ass sys col this 347
›st are very	Vehicle and aircraft washracks, hangar drainage, hobby shop, outdoor drainage areas, and old lab facilities	10-15 discharge to storm sewers, the remaining 10% discharges to Fairborn and 90% discharges to Dayton.	Undersized and old Improper maintenance. Flushing during periods of high flow.	Yes, on visit we saw oil that looked emulsified in a separator treating maintenance drains.	100 (Dayton), 94 (Fairborn)	NA	Dayton never samples the separators, Fairborn used to sample more frequently than they do now.	No	In the process of replacing the oldest and most worn separators		We als of dra har

›C=Point of Contact; POL=Petroleum, Oils, and Lubricants

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TABLE B-1. PRELIMINARY BASE LIST (CONCLUDED).

›Vs	Improvement Plans	Additional Comments
›	Replacement of separator at the auto hobby shop.	Patrick AFB is under the same command as Cape Canaveral Air Station, and someone at Cape Canaveral may have more information.
ut not &G. ecent s from ch. s for d, and	Education of users	Base is closing in September 1997.
›	3 washracks will be replaced with new separators. Base had considered closed-looped treatment system, but found that it was not economical because their sanitary costs are very low	NA
›	Some will be modified for waste upgrading.	NA
›	They will soon be feeding into a county treatment works and will replace 9 separators before that time	AETC has a contract with Vista Corporation to do a study on all separators at AETC bases for assessing the functionality of the systems. However, they will not collect samples. The AF contact for this project is Dennis Kirsch (210) 652 3420.
›	In the process of replacing the oldest and most worn separators	We have visited WP-AFB. We have also been provided with a 1994 survey of all base separators and technical drawings of the newest separators on base

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a. **Notices of Violations:**

- What agency regulates the quality of wastewater discharge from the base?
- How many NOVs related to O/W separator effluent streams been received over the past five years? Who were the issuing authorities?
- What were the limits for the contaminants causing the NOVs?
- What were the concentrations of contaminants that were in exceedance of discharge limits?
- Could each NOV be traced to a specific separator or set of separators?
- What were the results of the NOVs (e.g., fines, shutdowns, or increased maintenance costs)?
- What were the actions following the NOV that resolved the situation?
- Have any of the following actions been taken: taking the separators out of service; installing a new separator or pretreatment system; altering the influent stream; or renegotiating discharge limits?

b. **O/W Separators:**

- What are the number and general description of the O/W separators currently operating?
- What are the age and conditions of these separators?
- What types of the separators are they?
- Do coalescing devices, level/interface sensors, and pretreatment systems exist?
- What are the materials of the separation chambers, baffles, and pipes?
- Are these separators aboveground or belowground?

- Would you be able to provide flow/process diagrams including the location of any pipes into or out of the separator? (Influent pipes should indicate the source and effluent pipes should indicate the receiver.)

c. **Processes Supported:**

- What processes are supported by the separators?
- What are the basic activities that are responsible for generating the separator influent wastewater stream?
- What are the types and quantities of cleaning agents used in cleaning operations?
- What are the annual and peak flow rates from the process?
- What is the discharge receiver of the separator effluent? Designate the particular location, such as public-owned treatment works (POTW), federal-owned treatment works (FOTW), storm sewer, etc.

d. **Separator Maintenance Program:**

- What organization is responsible for separator maintenance?
- Do any scheduled maintenance activities exist?
- What are the individual base guidelines for the management of O/W separators? Some bases may follow guidelines such as *The Air Combat Command Management Guidance for Oil/Water Separators.*[B-3]
- Is effluent quality monitoring performed regularly? If available, obtain copies of analytical results.

e. **Separator Upgrade or Replacement Plans:**

- Are there plans to upgrade or replace separators?
- If upgrades are planned, what are the future plans?
- Are any pretreatment systems currently in operation or proposed for future use? (The information collected should

describe parameters and the treatment operations.) Potential operations may include chemical addition, dissolved air flotation (DAF), centrifugation, etc.

- Who are the technology providers?

2. Conclusions from Preliminary Survey

The information obtained from the telephone interviews is tabulated in Table B-1. A review of the data reveals the following:

a. Only two of the bases interviewed received NOVs for oil and grease (O&G) violations. Two other bases also had received NOVs, but the violations were related to heavy metals, chemical oxygen demand (COD), and total suspended solids (TSS). The lack of NOVs was due primarily to the lack of enforcement by regulatory authorities. Several bases had government-owned wastewater treatment plants that served as a backstop for the O/W separators.

b. The bases interviewed had a variety of O/W separators covering a broad range of ages, types, and conditions. Many bases recognized problems relating to the separator performance, maintenance programs, and improvement plans. Some bases had active or planned improvement programs.

c. Sampling data for effluent quality were nonexistent, but bases recognized that many separators were likely in disrepair and not functioning as designed. Further, over the years, buildings had changed functions but the O/W separators had not been modified. It was expected that some separators were no longer necessary while others were inadequate.

d. The bases interviewed shared common processes, although the types and conditions of the separators used for specific processes varied.

3. Final Base Selection

After reviewing the preliminary survey results, the ARCADIS Geraghty & Miller/Battelle team identified a list of 10 to 13 bases as the candidates for base visits. Criteria were subsequently developed for final base selection. These criteria are:

- Bases that share common processes but provide a variety of types and conditions of separators

- Bases that conduct operations of large volume and scale
- Bases that currently employ a range of separator technologies
- Bases that have ongoing improvement plans
- Bases that suspect an O/W emulsion problem
- Bases desiring to participate in the project by hosting a survey visit
- Bases that represent the major AF Commands

The following are the bases that were selected and, subsequently, approved by the project officer for base visits:

- Cannon AFB (Air Combat Command [ACC])
- Dover AFB (Air Mobility Command [AMC])
- Luke AFB (Air Education and Training Command [AETC])
- Mountain Home AFB (Air Combat Command [ACC])
- Wright-Patterson AFB (Air Force Material Command [AFMC])

Justifications for selection are discussed briefly below:

a. Cannon AFB (ACC):

- There are 24 separators on base; at least three of them are new separators with coalescing devices
- The base conducts a range of washing and maintenance operations
- The base point of contact (POC) is very concerned with emulsions in the O/W separators
- The base has recently installed four closed-loop RGF wastewater treatment systems. The systems perform separation using a gravity separator, centrifugal separation, filters, and chemical addition (for bacterial and odor control). Two more closed-loop systems will be installed.
- The base POC is very interested in participating in the study and encourages the ARCADIS Geraghty & Miller/Battelle team to visit and sample to determine if there is an emulsion problem

b. **Dover AFB (AMC):**

- The base POC suspects that many of the separators are not appropriately designed and are not maintained properly
- The base has various cleaning operations
- The base is in the process of replacing three existing separators
- The base POC is interested in participating in the project

c. **Luke AFB (AETC):**

- There are 66 separators on base (not all are operational). A few of the more recently installed aboveground separators have coalescing plates.
- Luke AFB conducts a range of washing and maintenance operations.
- The base operates a large number of aircraft (about 200 F-16s). As a result, cleaning and maintenance operations are performed frequently.
- One base POC suspects that there is an emulsion problem, particularly at a specific washrack. Wastestreams contain oils, detergents, solvents, and paint products.
- The base is working on an O/W separator management plan. A project currently in effect treats phenols and sulfides in O/W separator streams biologically. The base is investigating several other new technologies.
- The base POCs are very interested in participating in the study. The POCs have expressed a strong interest in new and innovative projects and have encouraged the ARCADIS Geraghty & Miller/Battelle team to visit.

d. **Mountain Home AFB (ACC):**

- Mountain Home is a large base with significant washing and maintenance activities. As the home of a composite wing, the base washes and maintains a wide variety of aircraft.
- There are 54 separators on base. Two or three RGF units are on base.
- The base POC believes that O/W emulsions are a big problem for the base. Emulsions are suspected in wastestreams from washracks and a corrosion control shop, and from any processes involving jet fuel.
- The base is involved in several projects aimed at replacing and rerouting most of the current separators. Many separators will be replaced with aboveground pretreatment systems, including mechanical separators.
- The POC is very interested in new technologies, wants to be proactive in addressing the problem, and is very interested in participating in the study

e. **Wright-Patterson AFB (AFMC):**

- Wright-Patterson AFB is a large base that performs many maintenance and washing activities
- There are 68 separators on base. Although most are older separators, four new separators with coalescing devices have been installed in the past two years.
- The base POC believes that the base has a problem with O/W separation and with O/W emulsions. She submitted a technology need form in 1994 for new treatment technologies for removal of low-level emulsified oils in contaminated wash water.
- The base is in the process of replacing the oldest and most worn separators

- The base POC and the director of the Environmental Management (EM) Office are very interested in participating in the project. The base POC hosted a visit by Battelle staff, and has been helpful in providing useful documents, including a recent survey of the separators, plans of the newest separators, and analytical results. The base is interested in participating in any pilot-scale work.

B. BASE NEEDS SURVEY OVERVIEW

As soon as the bases were selected, the POCs at each base were contacted to determine a list of separators to be surveyed. Preferences were given to those that may have effluent with high oil and grease content, use cleaning agents routinely, and generate large quantities of wastewater. Among the facilities that were suggested most frequently by the base POCs were aircraft washracks (including indoor corrosion control shop and outdoor washracks), vehicle washracks (including motor pool vehicle and auto hobby shop washracks), jet engine test cells and maintenance washracks, and aerospace ground equipment (AGE) washracks. Table B-2 presents the date(s) of visit(s), building numbers, and facilities surveyed. Sampling activities were canceled at several facilities because of non-operational separators, process equipment malfunctions, or ongoing construction activities.

A site survey form was used to document the information collected before and during the onsite survey at each base. The subjects included were base background information, existing separator operation and maintenance, NOVs, current and planned improvement plans, separators for further investigation, onsite survey results, and a sampling plan. The sampling plan included information such as sampling locations, sampling methods, and sampling time. Upon completion of the onsite survey, a base needs survey report was prepared for each base.

TABLE B-2. BASES AND FACILITIES SURVEYED.

Base	Visiting Date(s)	Building No.	Facility
Cannon	10/22-25/96	109/208	Aircraft maintenance hanger
		183	AGE washrack
		199	Corrosion control aircraft washrack
		223B	POL vehicle washrack
		438	Motor pool vehicle washrack
		495	Auto hobby shop washrack
		680	Jet engine washrack
Dover	11/6-8/96	101	Auto hobby shop washrack
		583	Aircraft washrack
		613	Engine test cell
		635	Motor pool vehicle washrack
		918	Diesel engine repair shop
		N/A	Industrial waste lagoon
		N/A	FRAMJ filters
Luke	11/13-15/96	234	Vehicle washrack
		403	Outdoor AGE washrack
		919	Outdoor aircraft washrack
		1016	Engine test cell washrack
Mountain Home	10/9-11/96	1100	Motor pool washrack
		1229	Wheel and tire shop
		1330	Corrosion control aircraft washrack
		1344	Engine test cell
		1349	Outdoor aircraft washrack
		1354	CE heavy equipment washrack
Wright-Patterson	10/3/96	55	Vehicle washrack
	12/10/96	93	AGE washrack
	12/16/96	4024	Aircraft washrack

N/A = Not applicable.

1. Cannon AFB

Cannon AFB is home to the 27th Fighter Wing, which contains F-111, F-111A, and F-16 aircraft. Several types of industrial facilities exist on the base, most of which are located on the base flight line. The facilities generating oily washwater include aircraft maintenance hangars, aircraft corrosion control facilities, electronic component repair facilities, aircraft fuel facilities, vehicle/equipment washracks, and support vehicle/equipment maintenance facilities.

Cannon AFB has 48 O/W separators; 44 of them are gravity-type separators. These separators generally are concrete basins or enclosed steel units; most of them are aged; 23 of the gravity separators were operational. The base has four state-of-the-art O/W separators manufactured by RGF; however, none of these units was operational during the visit.

The base uses official ACC guidance on the management of O/W separators.[(B-3)] In addition, the base's O/W Separator Management Plan specifies that each facility should conduct a monthly inspection of all separators used. However, of the four separators investigated during this study, none received periodic inspections. Two of the four separators were plugged with solids. Nevertheless, according to the Sverdrup Site Survey Report[(B-2)], most of the separators on the base had been tested, sampled, and/or serviced as part of a newly undertaken maintenance schedule and general day-to-day oversight. It was also observed during this survey that some separator vaults had been tested for leaks.

The effluent from the O/W separators has not been regulated. Since 1994, the base has begun to discharge nearly all O/W separator effluent to an FOTW which does not have a discharge limit for oil and grease. The State of New Mexico, however, does have a discharge limit of 100 mg/L for total petroleum hydrocarbons (TPH).

Cannon AFB plans to complete installation of four RGF closed-loop wastewater treatment systems. Two other systems are on order. These systems have modular components that include centrifugal separation, sand trap, microfiltration,

gravity separation, and ozone/H_2O_2 oxidation. The treated water will be reused for washing activities.

The design for a new wastewater treatment plant is currently underway, and the plant will be constructed to replace the existing facultative lagoon system. One of the lagoons may remain to serve as a treated effluent storage basin when the new plant is operational.

2. Dover AFB

Dover AFB is the home to the 436th Airlift Wing, better known as the "Eagle Wing," and the 512th Airlift Wing (Associate), the "Liberty Wing." Dover AFB also houses the largest aerial port facility on the East Coast, and is the focal point for cargo and passenger movement to Europe and the Middle East. The 436th Airlift Wing has 36 C-5s, the AF's largest cargo aircraft; it is the AF's only all-C-5 wing. The 512th Airlift Wing (Associate) is a subordinate unit of Headquarters 22nd AF (Reserve) and provides command and staff supervision, along with certain support functions, for assigned units during peacetime.

Dover AFB has 24 O/W separators to treat water from diked petroleum, oil and lubricant (POL) storage areas, and from aircraft washing and floor washing in other maintenance areas. Most of the separators are old, gravity-type concrete basins or enclosed steel units; only two contain coalescers. Fifteen of the separators discharge to a sanitary sewer system which, in turn, discharges to the POTW operated by Kent County. The base also has an industrial waste sewer (IWS) permit with Kent County. Seven of the nine separators discharging to a storm drainage system are associated with diked POL storage tanks. The remaining two are associated with industrial activities.

According to the base O/W Management Separator Plan, the Civil Engineering Operations Flight (CEO) is responsible for conducting periodic separator inspections including the determination of separator contents. The CEO, along with the Environmental Flight (CEV), also manages a contract to provide recurring cleaning of the separators. The CEV is responsible for annual sampling of separator holding tanks and disposal of free oil products from these tanks. The CEV also periodically updates

the O/W Separator Management Plan. Custodians of each building containing O/W separators routinely inspect their separators and report any problems to the Civil Engineer Squadron (CES).

The O/W Separator Management Plan has an explicit timetable of inspections and cleaning for most separators. However, it was evident from this survey that not all O/W separators receive adequate maintenance. Specifically, the O/W separator at Building 101 had not been cleaned out, and the FRAM© filters and O/W separator at Building 918 appeared to be poorly maintained. No other surveyed separators showed signs of poor maintenance.

Dover AFB is not required to perform routine monitoring of the effluent from their O/W separators. The base conducts monthly monitoring of the discharge from the IWS plant, which includes the effluent from the two FRAM© filters. At these discharge points, Dover AFB must maintain oil and grease at levels below or equal to 360 mg/L (24-hour average). Dover AFB expects that this limit may drop to 100 mg/L (24-hour average) in the future.

Dover AFB had several Notices of Non-Compliance by the Kent County Sewerage Authority for exceeding their National Pollutant Discharge Elimination System (NPDES) permit requirements for the base IWS. There have been exceedances for biochemical oxygen demand (BOD_5), oil and grease, and heavy metals such as cadmium, copper, and zinc. The most recent Notice of Non-Compliance, which was received in 1995, was for copper, zinc, and BOD_5. Although the oil and grease limit had not been exceeded, oil and grease may have contributed to an exceedance in the BOD_5 limit of 600 mg/L.

Dover AFB has an active separator improvement program. The separator at Building 918 may be removed after a closed-loop parts washer is installed. Alternatively, the effluent from the existing separator may be routed to the sanitary sewer. The separator at Building 613 is scheduled for replacement. The effluent from the separator at Building 914 will be routed to the sanitary sewer.

3. Luke AFB

Luke AFB is the largest fighter training base in the United States, and is home to the 56th Fighter Wing and the 944th Fighter Wing. Pilots are trained in the F-16 fighter. Approximately 200 aircraft are assigned to the base.

Luke AFB has 66 separators. Most of the separators are aged with some dating back to World War II. As building functions have been reconfigured, separators have not consistently been changed to match. Similar to those at Cannon and Dover AFBs, the separators at Luke AFB consist of gravity-type concrete pits with full-width baffles and aboveground or belowground steel chambers with attached remote oil storage tanks. Only a few of the separators are equipped with coalescing elements. A comprehensive inspection of all separators was performed by an engineering contractor in 1995.

Maintenance of separators is currently performed by the CES. A trailer-mounted storage tank with a pump is used to remove oily waste and sludge. Maintenance is scheduled on an annual basis unless problems arise earlier. The schedule may be refined as the base gains experience with the rate of oil/sludge generation at each separator.

There is no guidance at this time for monitoring conditions and performance of the separators, but the base would like to get the shops more involved. Base personnel are reviewing the ACC guidance document on the management of O/W separators. A base policy will be issued for inspection and cleaning.

Monitoring of oil and grease in separator effluent has not been performed because the base has a sanitary sewer system. The sanitary sewer has had problems exceeding phenol levels and has received one NOV for high phenol levels in discharge water. Some of the cleaning compounds used at the shops were thought to be responsible for the presence of phenol; but the problems were not completely solved by actions to eliminate the use of these phenol-containing cleaning compounds. To solve the problems, the base has implemented a bioaugmentation program using phenol-eating bacteria at the influent side of 51 of 66 separators. The preliminary results of the tests appear to be promising. As a side benefit, the sanitary sewage treatment plant

has observed a reduction in the visible oil and grease reaching the plant and fouling equipment at the incoming separators. The levels of oil and grease in the treatment plant influent had not been measured.

Luke AFB has formulated a strategy to upgrade/improve its separators. Because the base National Pollution Discharge Elimination System (NPDES) permits do not allow any separator effluent to flow to groundwater, the base is currently modifying such separators to redirect their effluent to the sanitary sewage treatment plant. In addition, the base will remove all separators that are no longer due to changes in building functions. Although separators with inadequate performance are due to be replaced, there was no replacement strategy at the time of the survey.

4. Mountain Home AFB

Mountain Home AFB is home to the 366th Tactical Fighter Wing of the ACC. The base was established in 1943 as a bomber base, and during WWII served several bombardment groups. The base was deactivated twice, between 1945 and 1948, and again between 1950 and 1951. In October 1991, Mountain Home AFB was converted from a Tactical Wing to a Composite Wing under the Defense Base Closure and Realignment Act of 1990. Operations now include support of fighter aircraft and larger and more varied aircraft, such as bombers, refueling tankers, and support aircraft.

Mountain Home AFB has a total of 54 O/W separators, which process most of the wastewater generated in industrial facilities on the base. The separators generally consist of belowground rectangular concrete detention basins or enclosed steel units. Some units are comprised of simple detention chambers, others have baffles, skimmers, or piping to a nearby holding tank. Although the configurations vary, all separators function as flowthrough chambers in which free oils and fuels separate into layers due to differences in specific gravity.

Many of the separators are old and have not been adequately maintained. Several of the O/W separators are considered as solid waste management units (SWMUs) and are scheduled for removal under a Resource Conservation and Recovery Act (RCRA) corrective action plan. The base has installed six new

aboveground mechanical separators with filters. None of these separators, however, have been operational due to repeated filter clogging. Further, an RGF closed-loop recycling system installed in Building 1330 for corrosion control operations has been out of order since soon after installation.

Many of the separators are routed to the storm sewer leading to a lagoon system. All new separators under the pretreatment project will discharge to a sanitary sewer. A wastewater treatment plant is being built to receive sewage from the sanitary sewer in 1997. By then, the base will have less concern over the quality of the effluent streams from the O/W separators.

The CES Water Department performs all maintenance on O/W separators. The department monitors a few critical locations, such as the Fire Department, and does spot checks at others. Otherwise, the department relies on shops to call for assistance if problems arise. The department responds to these calls by pumping the liquid contents into drums. In general, it is the responsibility of the industrial wastewater generators to arrange for wastewater disposal through the CEV and to shovel out any sludge at the bottom of the separators. Many separators have not been adequately serviced. Others are inspected as part of the internal shop inspections. Some are not inspected at all.

The base uses official ACC guidance[B-3] on the management of O/W separators. The CES has developed specifications for an O/W separator maintenance contract that covers the inspection and cleaning of O/W separators on base. An O/W separator inspection report was prepared in April 1996, detailing the inspection results, status, and physical data including drawings of each separator. Performance of the separators was not monitored in the past and no performance requirements exist. Sverdrup Environmental conducted a more complete sampling for 20 separators as part of a recent project.

5. Wright-Patterson AFB

Wright-Patterson AFB is the most diverse and organizationally complex base in the AF. There are 70 units representing 7 different Air Force commands and a host of Department of Defense (DoD) organizations. Missions include logistics

management, research and development, education, flight operations, and many other defense-related activities. Wright-Patterson AFB is home to the AF Material Command (AFMC), which has worldwide responsibilities for all of the AF's supply, depot maintenance, and repair functions. The Aeronautical Systems Center (ASC), a development component of AFMC, is located here as well. The ASC conducts research and development for all new AF aircraft and flight systems. The base is also home for Wright Laboratories, which is one of the four major laboratories operated by AFMC. The 88th Air Base Wing provides base infrastructure support.

Wright-Patterson AFB has 68 O/W separators, most of which are old, gravity-type underground concrete basins with single or multiple baffles. Recently, the base has purchased six new Highland underground separators with coalescing elements, four of which have been installed to replace the older separators. The effluent from the separators flows to either the storm or the sanitary sewer.

The 88th Air Base Wing/CES has hired a contractor to service the separators. The service includes inspecting, testing, and pumping out separators on a periodic basis. Prior to being pumped out, samples are taken from separators and analyzed to determine if the waste will be regulated as hazardous waste. Environmental Management (EM) issued a SOW establishing a maintenance contract with service contractors.[B-4]

Performance of the separators is not currently monitored on a regular basis by the AF. The two POTWs that receive wastewater are owned by the cities of Dayton and Fairborn. The Dayton POTW has established an oil and grease discharge limit of 100 mg/L, whereas Fairborn has a limit of 94 mg/L. Dayton has not performed any sampling, and Fairborn samples once a year. The base has not received any NOVs related to O/W separator effluent streams over the past 5 years.

C. PERFORMANCE EVALUATION OF SELECTED SEPARATORS

1. Separators Selected

Table B-3 presents the information pertinent to the separators selected for further investigation during each base visit. Most of the separators surveyed are old, gravity-type concrete basins or steel chambers subdivided with single or multiple

Base	Building/ Separator No.	Process Supported: Activity	Wastewater Generated[a] (gal/wash)	Wash Time[a] (hr/wash)	No. of Washing[a]	Pretreatn
Cannon	183/12	AGE washing	100	0.25	N.A.[b]	Sand tr.
	199/18	Aircraft washing	400	3	3-5/week	None
	495/32	Vehicle washing	50	0.5	20-30/day	Sand tr.
	680/33	Jet engine washing	100	0.5	1/day	Sand tr
Dover	101/4	Vehicle washing	50	0.5	Variable	None
	583/1	Aircraft washing	25,000	6	1/day	None
	613/3	Jet engine test cell	50	0.25	1/day	None
	635/5	Vehicle washing	50	0.25	Variable	Sand Tr
	918/2	Engine parts washing	60	0.5	1/day	None
Luke	234/234	Vehicle washing	20	0.1	30/day	Sand tr
	403/403	AGE washing	50	0.75	2/day	None
	919/919	Aircraft washing	100	4	2/day	Accumul. sump &
	1016/1016	Engine test cell	100	0.5	1/day	None
Mountain Home	1100/14	Vehicle washing	50	0.5	100-150/day	None
	1229/19	Wheel washing	50	0.3	2/day	None
	1330/26	Aircraft washing	400	4	1/day	Grit cha
	1344/33	Engine test cell	50	0.25	1/day	None
	1349/34	Aircraft washing	500	1	2/week	None
Wright-Patterson	55/38	Vehicle washing	50	0.5	50-80/day	Sand t
	93/47	AGE washing	50	0.5	3-4/week	Sand tr gravi
	4024/5	Aircraft washing	800	10	1-2/week	Non

(a)Estimated values obtained from base and facility POCs or through on-site observations

(b)N/A = Information not available.

(c)Old separator used as a storage sump.

1

TABLE B-3. SEPARATORS S
FURTHER INVES

o. f ing[a]	Pretreatment	Location	Material	Remote Oil Tank	Type	Age	No. of Stages	Capacity[a] (gal)
		Construction/Installation			Separator Characteristics			
(b)	Sand trap	In-ground	Concrete	No	Gravity	Old	2	400
veek	None	In-ground	Concrete	No	Gravity	Old	4	1,400
)/day	Sand trap	In-ground	Concrete	No	Gravity	Old	1	50
ay	Sand trap	In vault	Steel	Yes	Gravity	Old	2	5
able	None	In-ground	Concrete	No	Gravity	New	1	500
ay	None	In-ground	Steel	Yes	Coalescer	Old	3	1,500
ay	None	In-ground	Concrete	Yes	Gravity	Old	2	250
able	Sand Trap	In-ground	Steel	Yes	Gravity	New	3	3,000
ay	None	In-ground	Concrete	Yes	Gravity	Old	3	1,000
lay	Sand trap	In-ground	Steel	Yes	Gravity	Old	1	120
ay	None	In-ground	Concrete	No	Gravity	Old	3	1,000
ay	Accumulation sump & lift	Aboveground	Steel	Yes	Gravity	Old	1	10
ay	None	In-ground	Concrete	No	Gravity	Old	3	375
0/day	None	In vault	Steel	Yes	Gravity	Old	2	30
ay	None	In-ground	Concrete	No	Gravity	Old	2	300
ay	Grit chamber	Aboveground	Steel	No	RGF	New	2[c]	1,850[c]
ay	None	In vault	Steel	Yes	Gravity	Old	2	30
eek	None	In-ground	Concrete	No	Gravity	Very old	3	4,000
)/day	Sand trap	In-ground	Steel	No	Coalescer	New	3	3,000
veek	Sand trap & gravity	In-ground	Steel	No	Coalescer	New	3	550
veek	None	In-ground	Concrete	No	Gravity	Very old	3	5,750

2

E B-3. SEPARATORS SELECTED FOR FURTHER INVESTIGATION.

ır Characteristics

No. of Stages	Capacity[a] (gal)	Observed Conditions
2	400	Working condition
4	1,400	Working condition
1	50	Clogged with solids
2	5	Clogged with solids; water overflowed to remote oil storage tank
1	500	Needed free-product removal
3	1,500	Undersized
2	250	Ineffective; scheduled for replacement
3	3,000	Needed maintenance
3	1,000	Needed maintenance
1	120	Effluent pipe clogged with solids
3	1,000	Working condition
1	10	Unsecured flowrate control on sump pump
3	375	Working condition
2	30	Working condition
2	300	Working condition
2[c]	1,850[c]	RGF out of service
2	30	Observations could not be made
3	4,000	In disrepair
3	3,000	Working condition
3	550	Working condition
3	5,750	Working condition

3

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baffles. Only a few separators use coalescing elements to enhance separation. A majority of the separators are below grade or in vault with no leak-detection capabilities. The oil accumulated in the oil chamber either is pumped out periodically by service personnel or flows directly to a remote oil storage tank. The separators that support the same basic process across the surveyed bases vary greatly in size. For example, separators on vehicle washracks range from 30 to 3,000 gallons in size while flow rates of washwater are comparable. The feed to the separators often flows through a sand trap or a grit chamber to remove large particles before they enter the separators.

Many separators surveyed were either in disrepair or not well-maintained. When sampling was attempted, several separators were found to have excessive oily sludge and/or sediment buildup; some had clogged effluent pipes. At the same time, complex equipment, such as RGF closed-loop water recycling systems, were nonfunctional at the time of the survey due to improper installation, excessive operational and maintenance requirements, or inadequate operator training. These issues drive AF needs with respect to O/W separators, and are discussed in greater detail in Section III.D.

2. Sampling Strategy

At each base, influent and effluent samples were taken from the selected separators. Table B-4 summarizes the activities taking place during sampling as well as strategies for obtaining influent and effluent samples. The sampling strategies were formulated based on reports and/or drawings of the separators received from base POCs and/or vendors, discussion with base and facility POCs, and onsite observations.

3. Sampling Methods

Influent and effluent samples were collected using one of five methods:

- Vacuum collection using a hand pump
- Vacuum collection using a peristaltic pump
- Scoop collection using a Coliwassa unit
- Scoop collection using a dipping cup
- Collection from a washing unit drain hose

TABLE B-4. SAMPLING STRATEGIES FOR SELECTED SEPARATORS.

Base	Building/ Separator No.	Activity During Sampling	Sampling Location	
			Influent	Effluent
Cannon	183/12	Washing of a hydraulic test stand	Above sand trap in washrack drain	Separator discharge pipe
	199/18	No washing activity during sampling; washrack had been used during the week.	Grit chamber near the influent pipe	Effluent chamber near the discharge pipe
	438/29	Sampling canceled ! could not access effluent	No influent sample	No effluent sample
	495/32	Washing of two vehicles	Above separator sand trap chamber	Separator discharge pipe
	680/33	Washing of one hydraulic service cart	Above sand trap in the washrack drain	Separator discharge pipe
Dover	101/4	Washing of two vehicles	Separator inlet pipe	Three feet above bottom of final chamber
	583/1	Washing of a C-5 aircraft	Trench drain in washrack	Separator discharge pipe
	613/3	Washing of a C-5 aircraft engine	Floor drain gooseneck	One foot above bottom of separator discharge standpipe
	635/5	Washing of several vehicles and two empty hydraulic fluid drums	Above separator sand trap	Lift station receiving separator discharge
	918/2	Washing of diesel engine parts	Building trench drain	Separator discharge pipe
	NA/9	Sampling performed after sampling of washing activities at Buildings 583 and 613	Lagoon inlet pipe	Downstream of weir

TABLE B-4. SAMPLING STRATEGIES FOR SELECTED SEPARATORS (CONCLUDED).

Base	Building/ Separator No.	Activity During Sampling	Sampling Location: Influent	Sampling Location: Effluent
Luke	234/234	Car washing in bays	Carwash floor drain	Separator effluent pipe
	403/403	Washing of one hydraulic service cart	Trench drain	Separator effluent pipe
	919/919	Washing of four F-16 aircraft	Separator influent pipe	Above separator effluent port
	1016/1016	Washing test cell floor after engine tests completed	Separator influent pipe	Separator vent pipe
Mountain Home	1100/14	Vehicle washing	Separator influent pipe	Separator effluent pipe
	1229/19	Cabinet spray washer being operated to clean aircraft wheels	Washing unit drain hose	Separator discharge standpipe
	1330/26	An F-16 aircraft being washed in preparation for sanding	Grit chamber inlet	N/S
	1344/33	Cell floor being washed after an engine test	Floor drain	Discharge drainage ditch
	1349/34	No washing activity during sampling; a diesel generator washed the evening before sampling	Separator influent chamber	Effluent chamber near discharge pipe
Wright-Patterson	55/38	Washing of an Air Force bus	Above sediment trap	Separator final cell near effluent exit
	93/47	Washing of one hydraulic service cart	Wash rack floor drain	Separator discharge pipe
	4024/5	Washing of a C-141 aircraft	Wash rack floor drain	Separator discharge pipe

AGE = Aerospace ground equipment.
N/A = Not applicable.
N/S = Not sampled.

The apparatus used for the vacuum sample collection is shown in Figure B-2. A hand pump or a peristaltic pump was used to pull a vacuum on a 1-L specialty-cleaned I-Chem bottle through a 3-in Teflon™ tube that ran from the bottle to a sampling location. Once the bottle was about 80% full, the contents were proportionately distributed into four I-Chem bottles and one 500-mL plastic bottle to provide representative composite split samples. The procedure was repeated until all five sample bottles were filled. Samples collected with a scoop or from a washing unit drain hose also were equally divided into four 1-L and one 500-mL split samples. In general, the composite samples were collected over a duration of about 30 to 45 minutes or the entire wash/rinse cycle. The sample bottles were capped with Teflon™-lined lids, labeled, and visually inspected for sample appearance. The sample identification, sampling method, and visual description of each sample are presented in Table B-5.

For each influent and effluent stream, five split samples were collected: two 1-L split samples for O&G analysis; one 500-mL split sample for total suspended solids (TSS) analysis; and two 1-L split samples for surfactant analysis. The sample bottles were kept on Blue Ice☺ in sample coolers along with completed chain-of-custody forms. The samples for O&G and TSS analyses were shipped overnight to Lancaster Laboratories in Lancaster, Pennsylvania. The samples for surfactant analysis were shipped overnight to the laboratories at Battelle in Columbus, Ohio, where they were kept refrigerated until analyzed.

4. Analytical Methods

Samples of each separator's influent and effluent were analyzed for O&G and TSS. Upon receipt of these results, samples that had high effluent concentrations of O&G were analyzed further for surfactants. A summary of the analytical methods employed is presented in Table B-6.

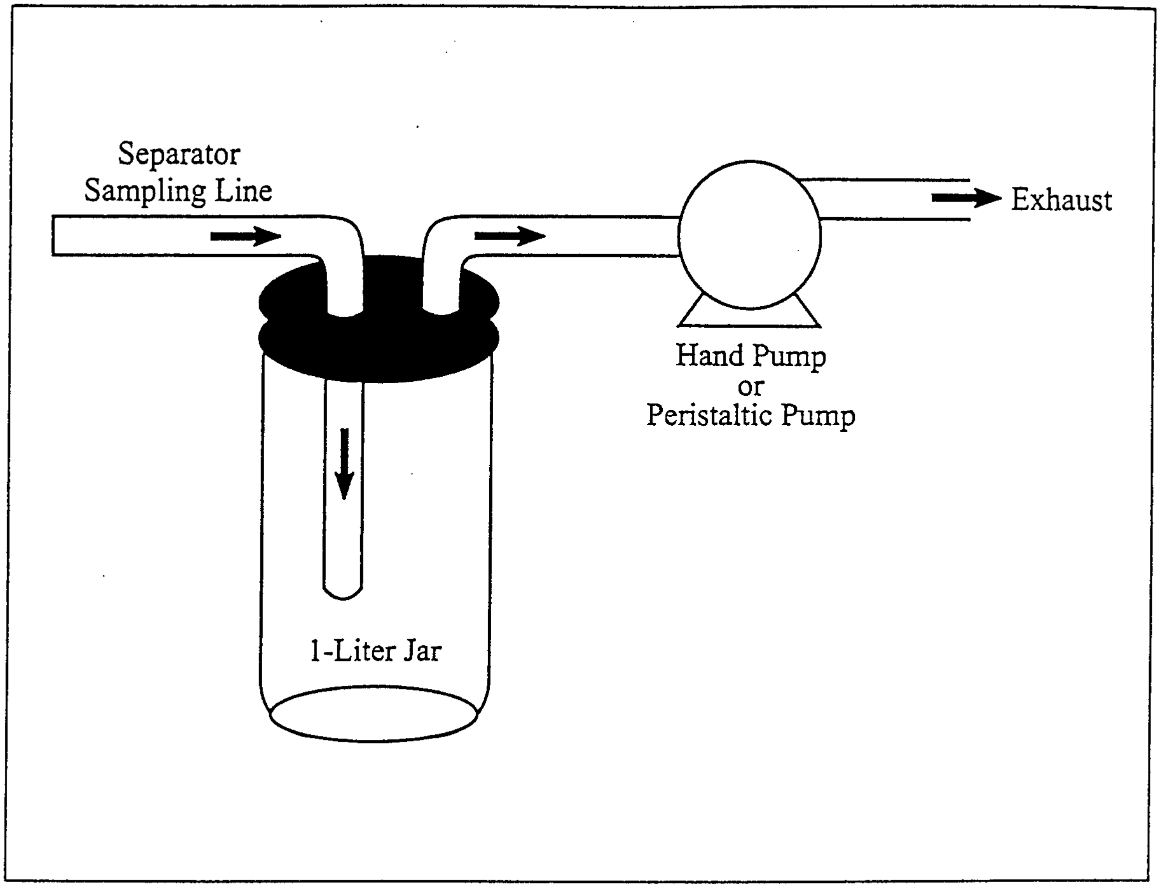


Figure B-2. Vacuum Sample Collection Apparatus.

TABLE B-5. OIL/WATER SEPARATOR SAMPLING LOCATIONS AND VISUAL OBSERVATIONS

Sample[a,b]	Sampling Method[c]	Sample Description
CN-183-E	HV	Cloudy, brownish-yellow, light oil sheen
CN-183-I	HV	Dirty brown, very soapy, gritty
CN-199-E	HV	Cloudy, lightly soapy
CN-199-I	HV	Cloudy, gritty, lightly soapy
CN-495-E	HV	Brown, dirty
CN-495-I	HV	Brown, dirty, very soapy
CN-680-E	HV	Gray, soapy
CN-680-I	HV	Yellow-brown
DV-FRAMJ-E	HV	Cloudy, soapy, oil sheen
DV-Lagoon-E	HV	Cloudy, soapy, oil sheen
DV-Lagoon-I	DC	Cloudy with oil sheen
DV-101-E	HV	Cloudy, lightly soapy
DV-101-I	HV	Soapy bubbles
DV-583-E	HV	Cloudy-gray
DV-583-I	HV	Cloudy-gray, visible oil sheen, gritty
DV-613-E	HV	Brown, dirty
DV-613-I	HV	Cloudy-white, dirty/oil, very soapy
DV-635-E	HV	Cloudy gray
DV-635-I	HV	Dirty brown, soapy, gritty
DV-918-E	HV	Dirty gray, soapy, visible oil sheen
DV-918-I	HV	Dirty brown, gritty, very soapy
LK-WWT-I	DC	Gritty with no visible oils or soap
LK-234-E	HV	Dark gray/black with sediment
LK-234-I	HV	Dark gray/black with sediment
LK-403-E	HV	Slightly cloudy, slightly soapy
LK-403-I	HV	Dirty brown, cloudy with oil sheen
LK-919-E	HV	Gray, cloudy, soapy
LK-919-I	HV	Gray, cloudy, soapy
LK-1016-E	HV	Gray, cloudy, with sediment
LK-1016-I	HV	Gray, cloudy, with sediment
MH-1100-E	HV	Soapy bubbles
MH-1100-I	HV	Brownish-white with soapy bubbles
MH-1229-E	HV	Brownish tint, clear
MH-1229-I	DH	Brownish-gold with fuel layer
MH-1330-E	HV	Brownish-gray
MH-1330-I	HV	Brownish-gray; sample appeared to be emulsified
MH-1344-E	C	Light brown with moderate turbidity; oily odor with sheen
MH-1344-I	DC	Yellowish-green with slight emulsification
MH-1349-E	HV	Whitish, opaque with oil sheen
MH-1349-I	HV	Whitish, opaque with oil sheen
WP-55-E	PV	Clear, minimal solids
WP-55-I	PV	Gray/black with sediment
WP-93-E	HV	Brownish, minimal solids, moderate fuel odor
WP-93-I	HV	Greenish brown, slightly soapy
WP-4024-E	HV	Brownish-white, slight oil sheen
WP-4024-I	HV	Milky-brown, soapy

[a]CN = Cannon AFB; DV = Dover AFB; LK = Luke AFB; MH = Mountain Home AFB; and WP = Wright-Patterson AFB.

[b]E = Effluent and I = Influent.

[c]C = Coliwassa; DC = dipping cup; DH = drain hose; HV = hand pump vacuum; and PV = peristaltic vacuum.

TABLE B-6. ANALYTICAL METHODS.

Analyte	Method	Method Description
Oil and grease	EPA 413.2	Extraction with freon and infrared spectrophotometric detection.
Total suspended solids	EPA 160.2	Filtration, drying, and gravimetric detection.
Surfactant isolation	SMEWW 5540B	Nitrogen gas sublation and drying.
Anionic surfactants	SMEWW 5540C	Methylene blue ion pairing followed by chloroform extraction and spectrophotometric detection.
Nonionic surfactants	SMEWW 5540D	Removal of ionic species with ion exchange resins followed by reaction with cobalt thiocyanate and spectrophotometric detection.

SMEWW = *Standard Methods for the Examination of Water and Wastewater*, 18th Edition (B-6).

O&G concentrations were measured using EPA Standard Method 413.2 (Total Recoverable Oil and Grease). In this technique, aqueous samples are acidified to a pH <2 and extracted with fluorocarbon-113. The O&G concentration of the extractant is then measured using infrared (IR) spectrophotometry. Positive interferences are provided by any extractable organic substances, which are soluble in fluorocarbon-113. Although nonionic and anionic surfactants have been shown to contribute positive bias to the method[B-5], this study was not designed to specifically address this problem.

TSS were measured using EPA Standard Method 160.2 (Nonfilterable Residue). In this method, the sample is filtered through a glass fiber filter and the collected residue is well-dried to a constant weight at 103° to 105°C.

Surfactant analyses were done using Standard Methods 5540B (Surfactant Separation by Sublation), 5540C (Anionic Surfactants as Methylene Blue Active Substances [MBAS]), and 5540D (Nonionic Surfactants as Cobalt Thiocyanate [CTAS]) from the *Standard Methods for the Examination of Water and Wastewater.*[B-6] Sublation was used to isolate surfactants from influent and effluent samples. The method involves bubbling nitrogen through a glass column containing an aqueous sample and an overlying layer of ethyl acetate. The surfactants present preferentially

move to the nitrogen/water interfaces and are carried into ethyl acetate and dissolved there upon the exit of the nitrogen bubbles. The ethyl acetate is separated, dehydrated, and evaporated to leave the surfactants as a residue. This residue is then analyzed separately for anionic and nonionic surfactants.

Anionic surfactants are analyzed by dissolving the residue in water, followed by adding methylene blue and chloroform in the resultant solution to form methylene blue/surfactant ion pairs in the immiscible chloroform. Methylene blue also can be added directly to an aqueous sample before chloroform extraction. The blue color in chloroform is measured spectrophotometrically at 652 nm. Dissolved solids detected using this technique are referred to as MBAS.

The nonionic surfactants are analyzed after removing the cationic and anionic surfactants using an ion exchange system. Nonionic surfactants are detected by the addition of aqueous cobalt thiocyanate solution to the sample. The nonionic surfactants react with cobalt thiocyanate to produce a product containing cobalt, which can be extracted into methylene chloride and measured at 620 nm. Dissolved solids detected using this technique are referred to as CTAS.

5. Analytical Results

The analytical results for the O&G and TSS are presented in Table B-7. Five of the O/W separators showed higher effluent O&G concentrations than influent concentrations. In three of these cases, i.e., CN-680, DV-583, and LK-234, the influent and effluent concentrations were close enough that the differences were probably due to experimental error associated with the sampling and analysis. In these cases, the values should be taken as essentially equal. In the other two cases, i.e., DV-101 and DV-635, the errors were high. Investigation of the chain-of-custody documents, interviews with the samplers, and the fact that the TSS measurements were lower in the effluent than the respective influent for all five samples ruled out the possibility of sample mislabeling. It was noted that the vacuum collection system did not work properly during the collection of DV-635 sample. It is possible that oil floating on the surface could have been pulled along with the sample. This may explain the much higher O&G concentration observed with DV-635 than measured with other vehicle

washracks. Higher effluent than influent TSS readings were noted in three cases, but in each case there does not appear to be any reason for concern.

As expected, a great deal of site-to-site variance was observed for the O&G concentrations in the washwater generated from similar processes. For example, the engine test cell separators at Mountain Home AFB and Dover AFB had the two highest measured influent concentrations, i.e., 2,980 and 10,900 mg/L, respectively, whereas the separator for Luke AFB had only 263 mg/L. The sampled AGE washracks at Cannon AFB and Luke AFB had influent concentrations greater than 700 mg/L, but the influent to the AGE separator at Wright-Patterson AFB had only around 100 mg/L. Also, the sampled aircraft washracks had influent concentrations as high as 1,220 mg/L at Mountain Home AFB and as low as 88 mg/L at Wright-Patterson AFB. The variance probably was due to process variability, such as the type or condition of the equipment/aircraft washed, type of detergents used, process discharging the wastewater, and the amount of water used per wash.

A significant site-to-site variance also was found for the influent TSS concentrations. For example, the TSS concentrations varied between 1,760 mg/L (at Mountain Home AFB) and 68 mg/L (at Cannon AFB) in jet engine washwater; between 1,630 mg/L (at Cannon AFB) and 82 mg/L (at Wright-Patterson AFB) in AGE washwater; and between 2,700 mg/L (at Mountain Home AFB) and 75 mg/L (at Wright-Patterson AFB) in aircraft washwater. The TSS variation in vehicle washwater was less significant, i.e., between 790 mg/L (at Wright-Patterson AFB) and 227 mg/L (at Cannon AFB).

The O/W separators for the engine test cells had the highest overall influent O&G concentrations. The separators were 51 to 97% efficient in removing the O&G, but still had relatively high effluent concentrations due to the high influent levels. The separators supporting the AGE washracks had the second highest influent O&G concentrations. These separators were 44 to 98% effective in removing the O&G, reducing the concentrations to less than 63 mg/L in all cases. The separators for the aircraft washracks also received influent with relatively high levels of O&G from 100 to 1200 mg/L. Most of these separators, however, showed inadequate O&G removal,

TABLE B-7. O&G AND TSS RESULTS FROM BASE SURVEY.

				Oil and Grease			TSS		
Base	Separator	Process Supported	Cleaning Agent	Influent (mg/L)	Effluent (mg/L)	Removal (%)	Influent (mg/L)	Effluent (mg/L)	Removal (%)
Cannon	CN-183	AGE washrack	Type I Aircraft Cleaner	2,930	63	98	1,630	72	96
	CN-199	Corrosion control aircraft washrack	Type I Aircraft Cleaner	100	91	9	105	28	73
	CN-495	Hobby shop washrack	Multiple	9	8	16	227	273	!20
	CN-680	Jet engine washrack	Simple Green	190	220	!16	173	126	27
Dover	DV-Fram	FRAM™ filters	Multiple	N/A[a]	117	N/A	N/A	30	N/A
	DV-Lagoon	Industrial waste lagoon	Multiple	2,080	124	94	30	45	!48
	DV-101	Hobby shop washrack	Multiple	66	117	!78	308	81	74
	DV-583	Aircraft washrack	Calla 8000, Astromat Orange	102	122	!20	203	50	75
	DV-613	Engine test cell	Citrikleen; Simple Green	10,900	553	95	1,170	389	67
	DV-635	Vehicle washrack	Citrikleen; Simple Green	600	1,850	!208	647	37	94
	DV-918	Diesel engine repair shop	Citrikleen	294	202	31	194	156	20
Luke	LK-WWT[b]	Wastewater treatment	Multiple	34	N/A	N/A	80	N/A	N/A
	LK-234	Vehicle washrack	VC2100	33	43	!30	612	339	45
	LK-403	Outdoor AGE washrack	N/A	717	37	95	623	24	96
	LK-919	Aircraft washrack	Penair HD-2	412	365	11	86	146	!70
	LK-1016	Engine test cell	Simple Green	263	130	51	68	62	9
Mountain Home	MH-1100	Vehicle washrack	Simple Green	15	12	19	510	42	92
	MH-1229	Wheel and tire shop	Tubmate	45	6	88	40	20	50
	MH-1330	Corrosion control aircraft washrack	Type II Cleaning Compound	702	N/A	N/A	260	N/A	N/A
	MH-1344	Engine test cell	Simple Green	2,980	82	97	1,760	540	69
	MH-1349	Aircraft washrack	Type II Cleaning Compound	1,220	490	60	2,700	60	98
Wright-Patterson	WP-55	Vehicle washrack	N/A	22	1	96	790	9	99
	WP-93	AGE washrack	Super Blastoff	104	58	44	82	27	67
	WP-4024	Aircraft washrack	Regen-B	88	46	48	75	23	69

[a]N/A = Not available.

[b]WWT = Wastewater treatment.

discharging above 100 mg/L. The vehicle washwater usually contained low levels of O&G.

The separators for aircraft washracks, in general, had the most difficulty performing adequate O&G separation. The same type of separators used to treat aircraft washrack wastewater, were used effectively for other applications. The surfactant analysis shown in Table B-8 found relatively high levels of nonionic surfactants in both the influent and effluent streams (see samples LK-919 and MH 1349). The results may indicate that the formation of stable emulsions was the cause of the high O&G retention in the effluent. On the other hand, samples DV-613, DV-635, and DV-918 showed much lower surfactant concentrations in the effluent than the influent, indicating removal of some surfactants with the captured oil.

Examination of the surfactant analysis results shown in Table B-8 revealed a few inconsistencies. For example, in two of the cases, DV-635 and MH-1349, cleaning agents with a single type of surfactant were used in the observed cleaning operations, yet both anionic and nonionic surfactants were detected in the respective samples. In the case of DV-635, it was known that both vehicle washwater and floor washdown water were fed into the separator. Although the vehicle washing used only a noninoic general-purpose detergent, the floor cleaning operation used Citrikleen and Simple Green, both of which contain anionic and nonionic surfactants. Residual anionic surfactants from Citrikleen and Simple Green apparently led to the detection of anionic surfactants in the samples. Further, the presence of both nonionic and anionic surfactants in the separator may explain why higher anionic surfactant concentrations were noted in the effluent than in the influent and why higher nonionic surfactant concentrations were found in the influent than in the effluent. In the case of MH-1349, it was not known whether cleaning agents other than the anionic Type II OctaKleen had been used in the area, although the use of nonionic surfactants prior to sampling was not unlikely. The presence of any nonionic surfactants could help explain the detection of nonionic surfactants in the respective samples.

TABLE B-8. ANALYSIS OF SURFACTANTS IN INFLUENT AND EFFLUENT SAMPLES.

	Cleaning Agent			Nonionic Surfactant as CTAS			Anionic Surfactant as MBAS		
Sample[a]	Trade Name	Surfactant Type[b]	Sample Volume (mL)	Absorbance (at 620 nm)	Mass[c] (mg)	CTAS (mg/L)	Absorbance (at 650 nm)	Mass[d] (mg)	MBAS (mg/L)
CN-680-E	Simple Green™	Both	5	0.196	1.84	369	0.293	0.113	22.6
CN-680-I	Simple Green™	Both	5	0.228	2.15	429	0.282	0.109	21.7
DV-613-E	Citrikleen™	Both	40	0.215	2.02	51	0.181	0.070	1.8
DV-613-I	Citrikleen™	Both	10	0.780	7.37	737	0.273	0.105	10.5
DV-635-E	General Purpose	Nonionic	10	0.060	0.56	56	0.166	0.064	6.4
DV-635-I	General Purpose	Nonionic	10	0.400	3.77	377	0.149	0.020	2.0
DV-918-E	Citrikleen™	Both	10	0.164	1.54	154	0.275	0.106	35.4
DV-918-I	Citrikleen™	Both	10	0.571	5.39	539	0.373	0.143	95.6
LK-919-E	PenairJ HD-2	Both	10	0.340	3.21	321	0.159	0.062	6.2
LK-919-I	PenairJ HD-2	Both	10	0.412	3.89	389	0.120	0.047	4.7
MH-1349-E	Type II-Octakleen™	Anionic	10	0.112	1.05	105	0.102	0.040	4.0
MH-1349-I	Type II-Octakleen™	Anionic	10	0.121	1.13	113	0.138	0.054	5.4

[a]E = Effluent, I = Influent.
[b]Both denotes both anionic and nonionic surfactants are present.
[c]Calibration Curve: CTAS (mg) = 9.464 (absorbance) - 0.011, r^2 = 0.998.
[d]Calibration Curve: MBAS (mg) = 0.3817 (absorbance) + 0.001, r^2 = 0.999.

The type of O/W separator employed was not found to be a good indicator of performance in this study. Nor was the surfactant type a good indicator of poor separator performance.

6. Data Quality Assurance

The accuracy and precision of the O&G analysis technique was measured by Lancaster Laboratories for each set of analyzed samples. The precision was measured by calculating the relative percent difference (RPD) of the replicate measurements. This is defined by:

$$RPD\,(\%) = \frac{|Value_1 - Value_2|}{\frac{(Value_1 + Value_2)}{2}} \tag{B-1}$$

where $Value_1$ and $Value_2$ are the first and the second measured values of the O&G content, respectively. The accuracy of the technique was measured by spiking the sample with a known amount of O&G standard and determining the percentage of the added amount which is detected. The recovery of the spike is defined by:

$$Recovery\,(\%) = \frac{Spiked\ Sample - Regular\ Sample}{Spike\ Added} \times 100\% \tag{B-2}$$

For the TSS measurements, only a measure of precision was made. This was given as an RPD as described above.

The precision of the O&G analysis as measured by the RPD was found to be less than 9% for all cases other than two sets of samples from Wright-Patterson AFB that had an RPD of 40%. The matrix spike recovery was found to be greater than 80% in all cases. The TSS measurements showed even greater precision, with a maximum RPD of 8%. It must be noted that a QA check for the analytical techniques was performed daily at Lancaster Laboratories and that the calculated RPD and spike recovery values were applied to all samples analyzed that day. The QA results indicated good data quality.

The sublation and surfactant analysis techniques were tested by analyzing samples of a known surfactant concentration. These samples were tested directly for CTAS and MBAS, and the values obtained were compared to those obtained after performing sublation. Approximately 93% of the anionic surfactant was recovered and detected. Approximately 94% of the nonionic surfactant was recovered and detected. These values compare favorably to the 94% and 92% recovery values noted in SMEWW Standard Method 5540 B.

D. CONCLUSIONS AND RECOMMENDATIONS

Reliable O/W separators are needed at AF bases, particularly for facilities such as engine test cells, AGE washracks, and aircraft washracks. The data from five representative AF bases indicate that O&G discharges from these operations may exceed permissible discharge limits. Large variations in O&G concentrations were measured from the representative O/W separators; however, the general conclusions are:

- Separators supporting engine test cells have the highest influent O&G concentrations which they partially remove, but the effluent O&G concentrations may still exceed discharge limits
- Separators supporting AGE washracks have high influent O&G concentrations which they effectively reduced to less than 63 mg/L in the representative samples
- Separators supporting aircraft washracks also have high influent O&G concentrations, and show minimal, or inadequate, removal
- Separators supporting vehicle washracks generally contain low influent O&G concentrations and should be a lower priority than the above applications for facility improvements

Most of the existing O/W separators are simple gravity devices that are old (>30 years) and have not been specifically designed for current service applications. The increased use of aqueous cleaning and environmentally acceptable detergents has changed the performance needs while the environmental regulations have become more stringent. Examples where new "state-of-the-art" O/W separators have been

installed complicate the problem by being too difficult and unreliable for typical AF applications. New O/W separators, as exemplified by RGF units including separation, filtration, and oxidation, are not being used for various reasons. Some are reported to be improperly installed and others are considered to require excessive operational and maintenance manpower that is not available. This experience leads to the conclusion and recommendation that simple gravity separators with internal coalescers may provide the most reliable long-term performance when properly selected and maintained for currently AF operations. Generally acceptable O/W separator performance is found at locations that have maintenance support available through contracts to remove accumulated sludge and oil, either at scheduled intervals or at the request of the responsible AF contact.

The recommendation from the Base Needs Survey is that priority O/W separators (such as engine test cells and aircraft washracks) need to be evaluated, modified, and/or replaced to meet current performance and environmental requirements. Part of this need may be satisfied by providing consistent and reliable information for:

- Evaluating current O/W separator performance
- Specifying an O/W separator for priority applications
- Operating and maintaining O/W separators for reliable performance.

Some applications and locations will require purchasing and installing new equipment to replace old, unserviceable, or undersize O/W separators others may simply require operator training and a reliable maintenance schedule.

E. REFERENCES FOR APPENDIX B

B-1. IT Corporation. 1995. *Transportable Wastewater Treatment: Technical Report on Heavy Metal-Bearing Wastewater of Sites Report.* Contract F41624-D-8137, Delivery Order 0003, Prepared for U.S. Air Force Human Systems Center (AFMC), Brooks AFB, Texas.

B-2. Sverdrup Environmental, Inc. 1995. *Industrial Waste Study — Phase II: Site Survey Report; Pollution Prevention Technical Report; Pretreatment Management Program Technical Report for Mountain Home Air Force Base,*

Idaho and Cannon Air Force Base, New Mexico. Contract No. DACW45-93-0013, Delivery Order No. 003, Prepared for Department of the Army, Omaha District, Corps of Engineers.

B-3. Air Combat Command. *The Air Combat Command Management Guidance for Oil/Water Separators.* 93-019, Air Combat command, July 6, 1993.

B-4. Wright-Patterson Air Force Base. *Statement of Work: Clean and Inspect Oil Separators and Settling Basins.* Project No. 921099. Wright-Patterson Air Force Base, Ohio, September, 1993.

B-5. Chen, A.S.C. 1996. *Using Ceramic Crossflow Filtration to Recycle Spent Nonionic Aqueous-Based Metal Cleaning Solution.* Contract Report CR 96.004, Naval Facilities Engineering Service Center, Port Hueneme, California.

B-6. *Standard Methods for the Examination of Water and Wastewater,* 18th ed. 1992. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Washington, DC.

APPENDIX C
TECHNOLOGY EVALUATION

This appendix presents a range of COTS and emerging O/W separation technologies by evaluating them on six criteria from applicability to cost.

A. TECHNOLOGY EVALUATION CRITERIA

Results from the base surveys conducted by the ARCADIS Geraghty & Miller/Battelle team were used to develop criteria to evaluate the applicability of O/W separation technologies selected for potential implementation at AF installations. The criteria are designed to address the needs and applicability at various AF O/W separator installations. The six evaluation criteria are as follows:

- General applicability
- Separation efficiency
- Operational and design requirements
- Maintenance requirements and reliability
- Commercial availability
- Cost

The subsections that follow present a brief discussion of each criterion. The criteria are not ranked in order of importance. Preference of one criteria to another must be determined locally for each specific O/W separator.

1. General Applicability

The status of the selected technology, range of flowrates the technology can process, complexity of installation of a new or retrofitted system, compatibility of the technology with the wastewater stream, and general suggestions for use will be included for discussion as it applies. Free oil refers to oil droplets, larger than 150 mm in diameter, in an unstable mixture with water while mechanically dispersed oil refers to oil droplets in the range 10 to 150 mm in diameter. Mechanically dispersed or mechanically emulsified oil is caused by agitation or high shear mixing and will separate into a separate oil and water phase if allowed to sit over time. Chemically emulsified or emulsified oil is created by surfactants, particles, electrical charges or other stabilizing

media and will not separate over time into a distinct oil and water phase. It usually consists of oil droplets less than 20 mm in diameter. Appendix A presents a detailed description of the various types of oil dispersions.

2. Separation Efficiency

Separation efficiency is the degree to which a separation technology can separate oil and grease from a waste stream. For example, a 98% separation efficiency means that only 2% of the influent oil will be released in the effluent stream. Conversely, separation limits may be given in units of ppm or mg/L oil concentration in the effluent. Efficiencies mentioned in this section are based on available literature and vendor information; they may not apply to every wastestream. Separation efficiency of a particular system is governed by a number of parameters such as the size and density of the oil droplets, stability of the O/W emulsion, density of the dispersed phase, and concentration of the contaminant oil and grease. Sources for oily wastewater streams at AF installations may be broadly categorized into four types, and some of the key characteristics of these streams are summarized in Table C-1.

TABLE C-1. OILY WASTEWATER STREAM SOURCES AND CHARACTERISTICS AT AF INSTALLATIONS[C-1].

Source	Average Oil and Grease Concentration, mg/L
Jet engine test cells	200-10,000
Aerospace ground equipment (AGE)	100-3,000
Aircraft washrack	100-1,500
Vehicle washrack	10-500

Federal guidelines require individual states, which, in turn, often require individual cities or other local governing bodies, to define discharge standards for wastewater. These standards generally require streams discharged to stormwater or the publicly-owned treatment works (POTW) to be below 100 mg/L Thus, selection of an O/W separation technology will largely be influenced by its capability to achieve the

required discharge standard. Operating examples for specific technologies are included when available to illustrate the conditions under which separation efficiencies were achieved.

3. Operational and Design Requirements

Personnel requirements, utilities, operational and mechanical complexity of the equipment, level of operator training, utility requirements, as well as special design and installation requirements are discussed under this criterion.

4. Maintenance Requirements and Reliability

Reliability expectations and the frequency and level of routine maintenance of each technology are assessed by this criterion.

5. Commercial Availability

The status and availability of the technology as COTS, and a partial list of established vendors, are covered by this criterion. A vendor list including addresses and contact personnel is presented in Table C-2. Neither ARCADIS Geraghty & Miller, Battelle, nor the AF are specifically endorsing any of these vendors or their products.

6. Cost

The capital and operating costs of typical units for each technology will be covered by this criterion. The costs are based on information from specific vendors and for specific equipment and are treated as random order-of-magnitude (ROM) costs for that class of equipment.

B. EVALUATION OF O/W SEPARATION TECHNOLOGIES

A wide variety of O/W separation technologies were investigated, and those technologies with potential applications to AF facilities are presented in this section. Although there are more technologies available for O/W separation, such as liquid liquid extraction and distillation, a preliminary review of the cost and complexity of operation, lead to the following short list of 10 technologies:

- Gravity Separators
- Coalescers
- Chemical Demulsification
- Dissolved Air Flotation (DAF)

TABLE C-2. LIST OF O/W SEPARATION EQUIPMENT VENDORS.

Advanced Processing Technologies, Inc. P.O. Box 58131 Salt Lake City, UT 84158 T: (801) 467-6111 F: (801) 467-6119	Bird Machine Co., Inc. 100 Neponset St. South Walpole, MA 02071 T: (508) 668-0400
AFL Industries 3661-F West Blue Heron Blvd. Riveira Beach, FL 33404 T: (407) 844-5200	Calgon Corp. P.O. Box 1346 Pittsburgh, PA 15230 T: (412) 777-8000
Alfa Laval Separation, Inc. 10 Commercial Blvd., Suite 214 Novato, CA 94949 T: (415) 883-8520 F: (415) 382-0308 POC: Richard Weeks	Carbtrol Corp. 51 Riverside Ave. Westport, CT 06479 T: (800) 242-1150 F: (203) 226-5322
American Felt and Filter Co. P.O. Box 951-A Newburgh, NY 12550 T: (914) 561-3560	Carr Separations, Inc. 46 Eastman St. Easton, MA 02334 T: (508) 238-1177 POC: Terry Cross
ARCADIS Geraghty & Miller, Inc. P.O. Box 13109 Research Triangle Park, NC 27709 T: (919) 544-2260 ext. 244 F: (919) 544-5690 POC: Dave Liles	CINC 3535 Arrowhead Dr. Carson City, NV 89706 T: (702) 885-5080 F: (702) 885-5087 POC: Carlo F. Luri
BPM Inc. P.O. Box 614 New Castle, DE 19720 T: (302) 328-6420 F: (302) 322-6062	Compliance Systems, Inc. 11 New Zealand Rd. Seabrook, NH 03874 T: (800) 678-2109
Baker Hughes Process Systems Houston, TX T: (713) 937-2400 POC: Anthony Pink	CUNO Separation Systems 50 Kerry Place Norwood, MA 02062 T: (617) 769-6112
BIOMIN, Inc. P.O. Box 200028 Ferndale, MI 48220 T: (810) 544-2552 F: (810) 544-3733	Davis Water and Waste Industries, Inc. 1828 Metcalf Ave. Thomasville, GA 31792 T: (800) 226-5775

TABLE C-2. LIST OF O/W SEPARATION EQUIPMENT VENDORS (CONTINUED).

Dorr-Oliver 612 Wheeler's Farm Rd. P.O. Box 3819 Milford, CT 06460 T: (203) 876-5503 F: (203) 876-5779 POC: Ed Sweeney	Hyde Products, Inc. 28045 Ranney Pkwy. Cleveland, OH 44145 T: (216) 871-1143
Dow Chemical Co. 2020-T Willard H. Dow Ctr. Midland, MI 48674 T: (800) FOAM-FREE	Industrial Filters Co. 9-T Industrial Rd. Fairfield, NJ 07004 T: (800) 822-4778 ext. 4
EFX Systems, Inc. 3900 Collins Rd., Ste. 1011 Lansing, MI 48910 T: (517) 336-4611 F: (517) 337-4610 POC: R.V. Rajan	Ingersoll-Rand Co. 200 Chestnut Ridge Rd. Woodcliff, NJ 0765 T: (800) 847-4041
Eimco Process Equipment P.O. Box 300 669 West 200 South Salt Lake City, UT 84110 T: (801) 526-2000 F: (801) 526-2005 POC: Asa Weber	J. R. Smith Manufacturing Corp. Division of Smith Industries P.O. Box 3237 Montgomery, AL 36109 T: (334) 277-8520 F: (334) 272-7396
Emulsions Control, Inc. 829 Hoover Ave. National City, CA 91950 T: (619) 336-6116 F: (619) 477-4376 POC: Sam Delchad	Komline-Sanderson, Inc. 12 Holland Ave. Peapark, NJ T: (908) 234-1000
Great Lakes Environmental, Inc. 315 South Stewart Addison, IL 60101 T: (708) 543-9444	Lakos Laval Corp. P.O. Box 6119 Fresno, CA 93703 T: (209) 255-1601
Great Lakes Environmental, Inc. (Organoclays) P.O. Box 480 Wasco, IL 60183 T: (708) 377-0711 F: (708) 377-1130	Lormar Reclamation Services 28450 D Broce Dr. Norman, OK 73072 T: (405) 321-0636

TABLE C-2. LIST OF O/W SEPARATION EQUIPMENT VENDORS (CONTINUED).

MSC Liquid Filtration Corp. 10 Dusthouse Rd. Enfield, CT 06082-1547 T: (860) 749-8316 F: (860) 763-3354 POC: Richard Johnson	Otto H. York Company, Inc. 42 Intervale Rd., P.O. Box 3100 Parsippany, NJ 07054 T: (201) 299-9200 POC: Thomas Flannery; (408) 734-2525
Membrex 155 Route 46 West Fairfield, NJ 07004 T: (800) 777-5242	Precision Environmental Systems 3300 E. Pythian Springfield, MO 65801 T: (800) 644-0454
Mercer International P.O. Box 540 39 West Main St. Mendham, NJ 07945 T: (201) 543-9000 F: (201) 543-4343 POC: David A. Goding	RGF Environmental Systems, Inc. 3875 Fiscal Court West Palm Beach, FL 33404 T: (800) 842-7771 F: (407) 848-9454 POC: Phillip Kircher
Metcalf-Eddy P.O. Box 1500 Sommerville, NJ 08876 T: (908) 685-6100 F: (908) 685-6106	Seprotech Systems, Inc. The DuPage Technology Center 100 Bridge St. Wheaton, IL 60187 T: (708) 871-5800 POC: Trevor Cook
Nalco 1 Nalco Center Naperville, IL 60566 T: (708) 305-1000	Sher-Fran Corp. 459 Marion Ave. Plantsville, CT 06479 T: (860) 628-8684 F: (860) 621-7528
North American Technologies, Inc. 9818 Wilcrest Houston, TX 77099 T: (713) 662-2699 F: (713) 494-2434 POC: Robert DeRoche	U.S. Filter 181 Thorn Hill Rd. Warrendale, PA 15086 T: (412) 772-0086
Osmonics, Inc. 5949 Clearwater Dr. Minnetonka, MN 55343 T: (800) 848-1750	VORTOIL Separation Systems 6650 Roxburgh, Suite 180 Houston, TX 77041 T: (713) 9372400 F: (713) 937-2401 POC: Anthony Pink

TABLE C-2. LIST OF O/W SEPARATION EQUIPMENT VENDORS (CONCLUDED).

Wheelabrator Engineered Systems, Inc. 28 Cook St. Billerica, MA 01821 T: (800) 359-2828	Zenon Burlington, Ontario Canada
Yardney Water Management Systems, Inc. 6666 Box Springs Blvd. Riverside, CA 92507 T: (909) 656-6716	

- Centrifugal Separators
- Air-Sparged Hydrocyclones (ASH)
- Depth Filtration
- Membrane Separation
- Electrical Field Separators
- Biotreatment

This broad range of technologies is evaluated based on the criteria of Section A. Figure C-1 presents an overview of the technologies and specific examples of O/W separators under each technology type described in Appendix D. Description of the working principles of these technologies is presented in detail in Appendix D.

Mention of commercial products and their capabilities is aimed at providing the reader with examples and should not be construed as a direct or implied endorsement of the products or companies. Furthermore, drawings and pictures of different technologies are included to serve as illustrative examples of a class of equipment not endorsements of the specific brand-names used.

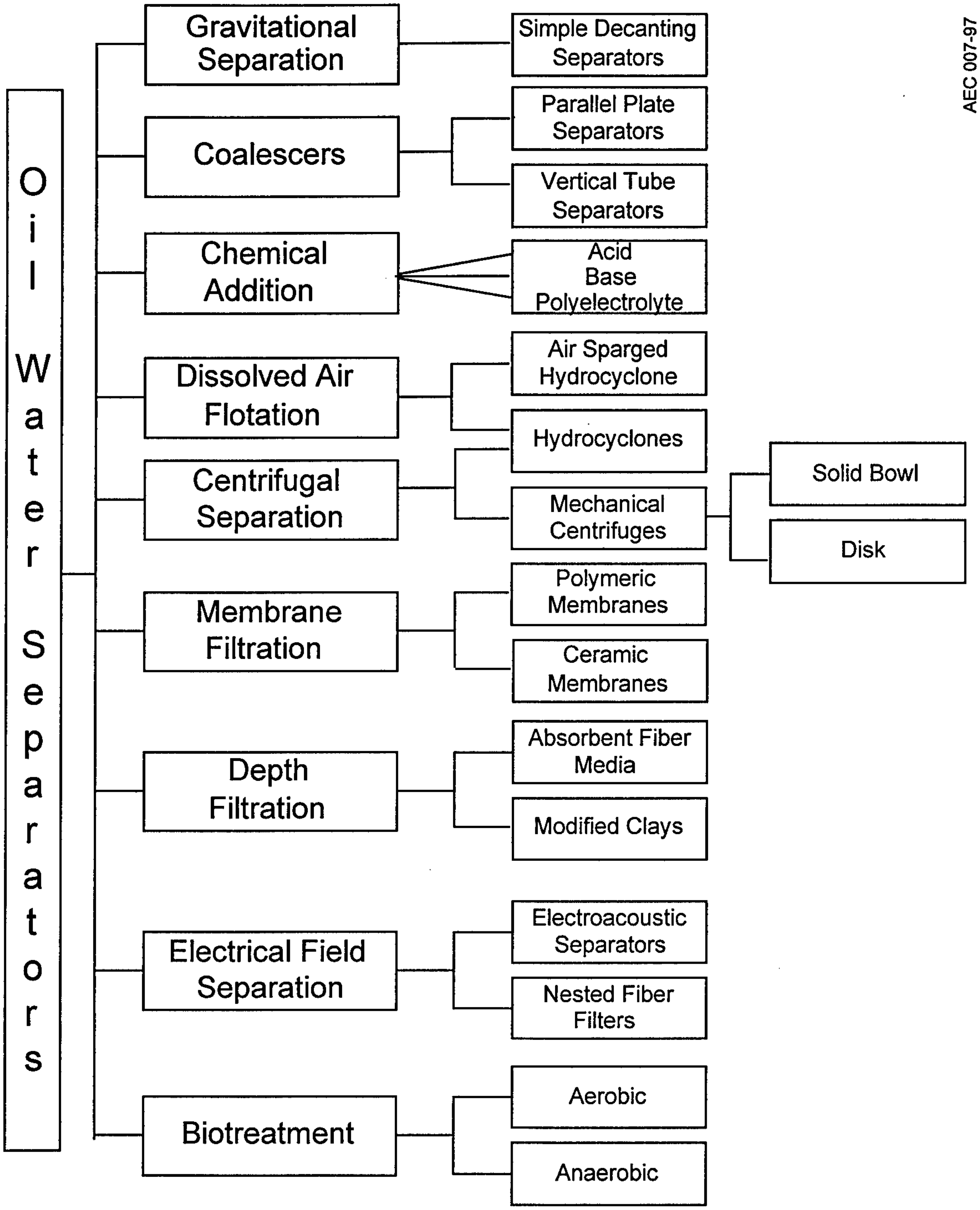


Figure C-1. Overview of Selected O/W Separation Technologies.

1. Gravity Separation

a. General Applicability

Gravity separators are perhaps the most widely used O/W separation equipment for treating mechanically dispersed and free oil contaminated wastewaters. They are also the most popular type of separators used in the AF. Gravity separators are available in a wide variety of designs with the most elementary form being simple-decanting separators. Simple decanting separators are essentially holding tanks through which the O/W mixture flows at a velocity that provides sufficient residence time in the tank for the oil droplets to rise to the surface. A description of the working principles of simple-decanting separators is presented in Appendix D. Simple decanting separation techniques have been standardized by the American Petroleum Institute (API) with a set of criterion that are as follows: the minimum operating temperature is 40°F; the maximum value for the specific gravity of the suspended oil is 0.85; and the minimum oil droplet diameter is 150 μm.

Gravity separation equipment can be designed to handle a wide range of flowrates at relatively low costs. They are also capable of handling fluctuations in flowrate and heavy particulate loading as long as sufficient residence time is allowed for the oil to coalesce. The primary purpose of simple decanting separators is to remove free oil, and they typically precede other O/W separation equipment. Simple decanting separators can be enhanced to treat mechanically dispersed oil droplets of very small sizes through the use of coalescing devices. While the primary function of coalescing devices is to enhance gravity separation, an entire industry has been generated for coalescing media manufacture, and they are discussed separately in the next section.

The size of gravity separation vessels depends on the flowrate of the wastewater to be treated. Individual wastestreams need to be analyzed as a gravity separator is best suited for the removal of free oil and is not applicable to all oily wastestreams. A simple preliminary analysis is to take a sample of the wastewater in a small jar, shake the jar for thorough mixing, and allow the jar to sit for 1 hour. The

visible separation at the end of that time is analogous to the separation that can be expected from gravity separation.(C-2)

If the densities of the dispersed phases are similar or if the dispersed phase droplets are very small, the separation velocity will be very low, limiting the separation efficiency of gravity separators. Detergents and other surfactants tend to emulsify oils, keeping them as very small droplets and preventing coalescence, thereby limiting the efficiency of gravity separators for oil water mixtures which contain detergents. Chemically stabilized emulsions generally require pretreatment before they can be separated in a gravity separator.

b. Separation Efficiency

Gravity separators are very effective in separating free oil. Desired effluent concentrations achieved by allowing a sufficient residence time and are not affected significantly by inlet concentrations. Some commercial gravity separators offer emulsion breaking systems as an integral part of the gravity separation unit; thus, these systems achieve partial separation of previously mechanically emulsified oil as well.

c. Operational and Design Requirements

Gravity separators are relatively simple equipment in comparison to other O/W separation technologies. Typically they contain no moving parts. The flowrate of the wastewater to be treated determines the size of the gravity separation unit. The oil separation velocity is typically calculated using Stokes' Law; the separation velocity in turn determines the maximum flowrate through the vessel and the size of the vessel. Discharge requirements for the wastewater should be determined and the vessel sized to allow the required residence time.

d. Maintenance Requirements and Reliability

Simple decanting separators when operated within their design specifications are reliable equipment and require relatively low levels of maintenance when compared to other types of O/W separators. Since simple gravity separators are used as first stage separation equipment, influent to these devices contains greater amounts of solids. Heavy, oily particulate will collect in the bottom of the separator and require periodic dredging or emptying. Therefore, routine maintenance may involve

removal of solids from the decanter bed which may have to be disposed of as hazardous waste. Equipment reliability and efficiency are typically reduced when routine clean-up measures are not followed and/or the equipment is operated improperly, such as when it is operated at higher than design flowrates.

e. Commercial Availability

Gravity separation equipment is COTS technology widely used for O/W separation in a variety of industries. A number of companies manufacture gravity separation equipment. Some of the established vendors include: Great Lakes Environmental, Inc.; Mercer International, Inc.; RGF Environmental Systems, Inc.; Eimco Process Equipment; Dorr-Oliver, Inc.; and J. R. Smith Company. Addresses and contact telephone numbers for these companies are listed in Table C-2.

f. Cost

The cost of gravity separation units varies widely depending on the application and the manufacturer. Gravity separators are commercially available in sizes ranging from small-scale units to units capable of handling thousands of gallons per minute (gpm). Units in the size range of 5 to 300 gpm range from $5,000 to $60,000. Installation costs are additional and vary with the application. The operating cost of gravity separation equipment is relatively low in comparison with other types of separators.

g. Advantages

Gravity separators are a mature technology and are widely used in industry to treat a broad spectrum of oily wastewaters. Their large volumes allow them to act as a buffer for spikes in concentration and flowrate to reduce shocks to downstream treatment systems. They efficiently remove non-emulsified oils to acceptable levels of concentration in most cases. Relatively simple to operate and in requiring little maintenance they are ideal to use as the first treatment device in a systemic approach to O/W separation. They are also relatively inexpensive and can be used in conjunction with other O/W technologies to reduce the overall cost of the treatment system.

h. Disadvantages

Gravity separation equipment are relatively large in size. The separation efficiency of gravity separation units is reduced when they are operated at flowrates greater than their design capacities. Without pretreatment for demulsification, gravity separators are not capable of removing emulsified oils from the wastewater. Residence time requirements sometimes make gravity separation a time consuming process.

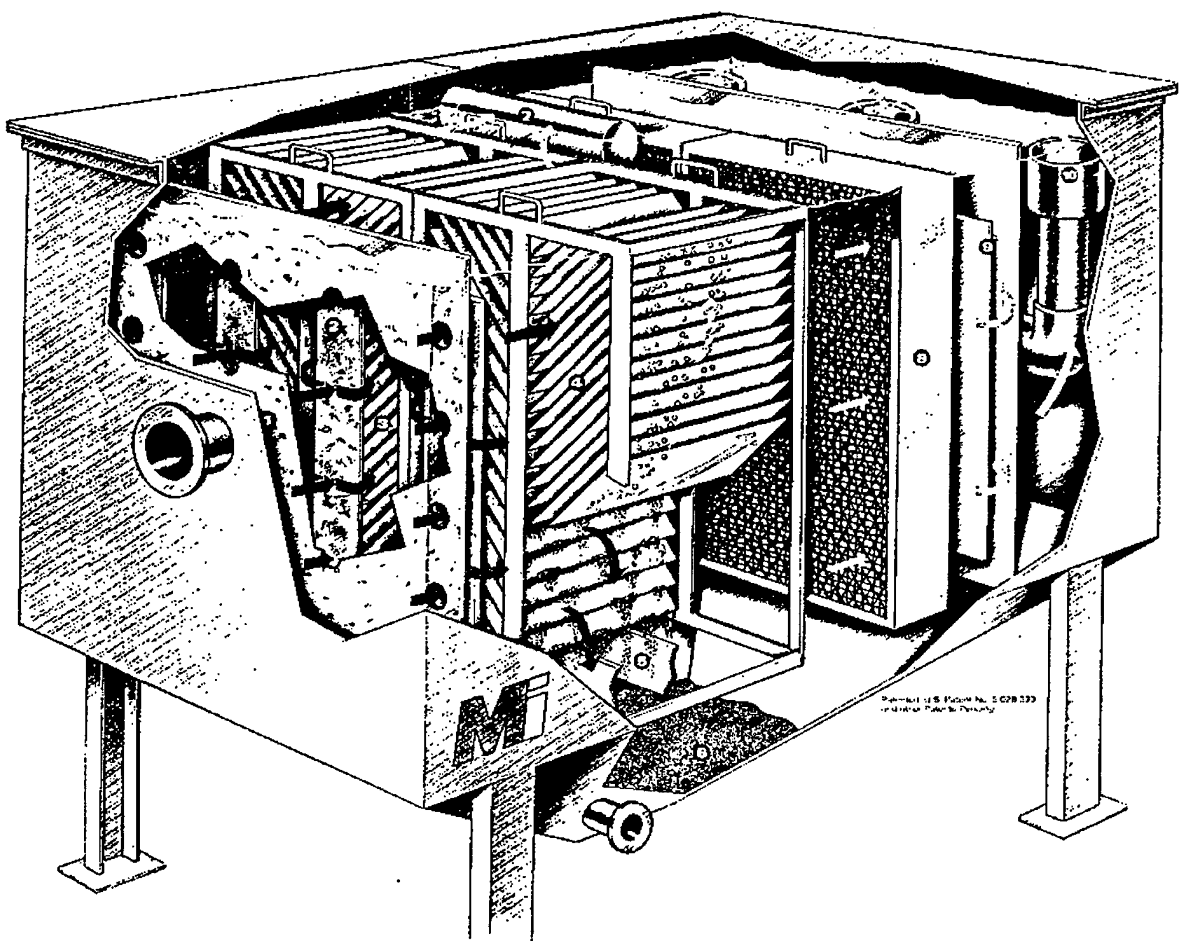
2. Coalescers

a. General Applicability

Coalescing devices are used to enhance gravity separation of oil and water. The coalescing process is accelerated by forcing the dispersion to flow through a porous oleophilic media. Small oil droplets adhere to this surface and coalesce into larger drops which release from the oleophilic surface to separate more rapidly from the water phase. A detailed description of the working principles of coalescers is presented in Appendix D.

Coalescers are a COTS technology. However, continuous advances in the development of new coalescing media are being made, especially in the ability to treat emulsified oil.[C-3] Coalescing devices are capable of removing mechanically dispersed oil droplets of very small diameter. Parallel corrugated plate coalescing elements are used for large (~100 μm) size oil droplets, while mesh elements can be designed to separate oil droplets with sizes in the sub-micron range. [C-4] Figure C-2 shows the cut-away picture of a stand-alone gravity separator with parallel-plate and mesh type coalescing elements.

Coalescing elements are ideal retrofits to improve the performance of existing gravity separation equipment. Designing a gravity settler with coalescing devices typically results in a smaller unit than one designed to handle a comparable flowrate of oily wastewater without any coalescing devices. While in general these devices are not capable of coalescing emulsified oil, developments in coalescing media technologies such as specially coated ceramic media have shown to be effective in removing some types of emulsified oils.(C-3)



1. Inlet Chamber
2. Distribution Baffles
3. Coarse Separation Zone
4. Multi-Pack™ Coalescer
5. By-Pass Prevention Baffles
6. Solids/Sludge Chamber
7. Oil Skim Pipe
8. NSA™ Secondary Coalescer
9. Outlet Distribution Baffle
10. Outlet Manifold

Figure C-2. Parallel Plate Gravity Separation Unit with Mesh Coalescing Elements. (Mercer International.) (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)

b. Separation Efficiency

Coalescing devices are widely used in process industries. The following examples show how coalescers have been used to treat wastewater in industry. One type was tested as an in-tank separating device for use aboard ships. The discharge from the separator contained less than 20 mg/L of oil and grease 99% of the time and below 100 mg/L 100% of the time.[C-5] This ability to reduce the suspended oil to less than 100 mg/L is typical for an industrial coalescer.

There have been many studies on the performance efficiency of parallel-plate separators. Fairly common results for a gravity separator containing parallel plate coalescing elements show 98% separation efficiency for a toluene/water mixture.[C-6] The separation efficiency dropped to 92% when 200 mg/L surfactant was added. Another source reported that the use of parallel-plate separation reduced a wastestream with influent oil of 10,000 mg/L to 20-50 mg/L.[C-7]

Another study reported that a coalescing device of co-knit fiberglass and wire reduced oil and grease concentrations in two separate influent streams, from 130,000 and 400,000 mg/L to below detection limits.[C-8] However, in this study, the coalescing devices were plugged rapidly, causing efficiency to rapidly decrease over time. To efficiently separate using this media, the influent must be particulate free or the coalescer surface must be kept clean which usually requires a high degree of maintenance and monitoring during operation. Plugging of the coalescing pads could be reversed by continuously injecting a stream of pure solvent into the influent.

Well-designed coalescers operating on a particulate free feed stream are typically capable of removing mechanically dispersed and free oil (non-emulsified oils) to concentrations of less than 10 mg/L. Separation efficiency depends on the oil droplet size and the type of coalescing elements used. Emulsions generally require chemical pretreatment before they can be separated with coalescers, although companies involved in wastewater treatment equipment are continuously researching and developing new types of coalescing technologies.

An example of this new technology is an oleophilic amine-coated ceramic chip designed to separate suspended and dissolved hydrocarbons, most mechanical emulsions, and some chemical emulsions from aqueous solutions. This new coalescer surface was developed and demonstrated by North American Technologies Group, Inc., and the U.S. EPA, under the Superfund Innovative Technology Evaluation Program between 1992 and 1994. The developer claims to have achieved concentrations of less than 7 mg/L of oil and grease in the treated effluent.

c. Operational and Design Requirements

Coalescing elements do not require external power for separation as they typically contain no moving parts. The coalescer vessel must be sized to provide optimum coalescence and separation. The diameter of the vessel should be large enough to provide a superficial velocity low enough to allow the droplets to grow in size. A prefilter to remove suspended solids may have to be used. Fine mesh coalescing elements can cause a significant pressure drop in the flow, especially in the presence of suspended solids that could block flow through the elements; this must be taken into consideration during the design process.

d. Maintenance Requirements and Reliability

Although most coalescers are designed to facilitate solids removal to minimize plugging, it will be necessary to periodically clean the media and remove solids from the unit. A build up of solids on the plate will drastically reduce separation efficiency. When operated within design specifications, coalescers are generally robust and reliable equipment. Maintenance typically involves routine inspection of coalescing elements often with occasional cleaning or periodic replacement of elements in some cases.

e. Commercial Availability

Coalescers are a widely used technology in the liquid/liquid separation industry. Most gravity separation units have some form of coalescing devices present. Many companies are involved in the manufacture of coalescing equipment and a few of the established ones include: RGF Environmental Systems;

Mercer International; Otto H. York Company, Inc.; and Great Lakes Environmental, Inc. Addresses and contact telephone numbers for these companies are listed in Table C-2.

f. Cost

The cost of coalescing equipment vary widely depending on the application, type of coalescing element used and the manufacturer. Mercer International offers a complete gravity separation unit with coalescing elements, designed to handle solids loading as well as oil in water (Figure C-2). A 5- to 10-gpm unit costs about $5,000, a 50-gpm unit about $15,000, and a 100-gpm unit about $20,000.

RGF Environmental offers a coalescing O/W separation system (Model OWS-50A) that is capable of handling a wastewater flowrate of 50 gpm, and costs approximately $8,000.

Installation costs, excluding shipping and handling, are minimal for stand alone units and slightly higher for retrofit operations. The cost of operating the Model OWS-50A is between $10 and $30 per thousand gallons of wastewater treated. The labor costs of operating coalescer equipment are not expected to exceed the cost for operating gravity separation equipment.

g. Advantages

Coalescers are very efficient devices for the separation of non-emulsified oil from wastewater and are relatively low maintenance systems when properly operated. When installed in gravity separators, they can significantly reduce the necessary size of the unit.

h. Disadvantages

The main disadvantage of using coalescing equipment is that they are not generally applicable to the separation of emulsified oils. Another disadvantage is fouling by the media by suspended solids. If the coalescer's surface is covered or blocked by sludge, the separation efficiency decreases and, if not cleaned, the coalescer might become entirely blocked to flow.

3. Chemical Demulsification

a. General Applicability

While chemical addition is not a separation technology in and of itself, it is an important prerequisite in many O/W separation systems where emulsified oil is present. Demulsification of chemically emulsified oil is often achieved by the addition of organic polyelectrolytes to the O/W mixture. Heating the emulsion to reduce the density of the oil phase and changing the pH to alter surface charges are also typical ways to break emulsions. The type of chemicals used are commonly referred to as "polymer addition" within the O/W separation industry and their effectiveness depends on characteristics such as pH of the waste stream and the reason for the stable emulsion (e.g., type of surfactant). Appendices A and D present detailed discussion of the working principles of demulsification.

In the wastewater treatment industry, most systems using mechanical O/W separation technologies also use some form of an emulsion breaking system to destabilize emulsified oils. Manufacturers of O/W separation systems often provide chemical and/or other demulsification systems as an integral part of the overall treatment system. The demulsification systems usually consist of a chemical holding tank and metering system to add the demulsifiers to the wastestream.

b. Separation Efficiency

The destabilizing efficiency of the chemical added depends on choosing the right polymer. Because chemical addition works by imbalancing and neutralizing the surfactant micelles which keep oil droplets from coalescing, a polymer that works quite well on a cationic surfactant induced emulsion will have little to no effect on an ionic surfactant induced emulsion. The nature of the emulsion and the characteristics of the wastewater must be well understood before an appropriate polymer is chosen. Once the right polymer has been selected, destabilization of the emulsified oil is often almost complete.

Laboratory tests by Little and Patterson[C-9] indicated that certain quaternary ammonium compounds were effective in breaking 5% oil-in-seawater emulsions over a 20-hour period at temperatures ranging from 4° to 45°C. The

demulsifier concentration required to break the emulsions generally ranged between 1 to 2% at 4°C and 0.1 to 0.2% at 45°C. At the lower temperature, the oil concentration in the separated water ranged from 100 to 500 mg/L. At the higher temperature, the highest oil concentration was measured to be 55 mg/L, while most of the samples measured 25 mg/L.

c. Operational, Design, Maintenance Requirements, and Reliability

Polymer addition for emulsion destabilization is usually included as part of the O/W treatment train. Typically very small quantities of the demulsifier are needed compared to the flowrate of the wastewater. Suggested quantities from the literature are usually 150 to 1,500 mg/L. Polymer dispensing systems are simple and are not a significant factor in the overall operation and maintenance of the separation system. A tank for mixing the polymer into the emulsion can be combined with mixing induced in air flotation, but is usually carried out in a separate vessel. Some systems use gravity separation to remove most of the free oil, followed by chemical addition and concluded with dissolved air flotation or some other high-efficiency separation technology.

d. Commercial Availability

Addition of chemical destabilizers is a mature technology. A number of polyelectrolyte emulsion destabilizers are available from various vendors, and some of them include: Emulsion Control, Inc.; Nalco; Dow Chemical Corp.; Calgon Corp.; Great Lakes Environmental, Inc.; and Lormar Reclamation Services. Addresses and contact telephone numbers for these companies are listed in Table C-2. However, manufacturers of integrated oily wastewater systems typically provide a suitable emulsion breaking system as part of the treatment package.

e. Cost

The cost of chemical demulsifiers depends greatly on the application and varies widely. Information obtained from vendors of demulsifying agents

f. Advantages

Chemical demulsification is usually efficient, inexpensive, and can be used in conjunction with most mechanical separation processes. Once the concentration to destablize an emulsion is determined, the operator needs do little more than ensure this amount is added and mixed.

g. Disadvantages

The major limitation of chemical addition for treating oily wastewater is that it produces a large amount of sludge, which requires further handling and disposal. A treatability study is usually required for identifying the correct polymeric destabilizing agent and to establish the dosage. Another drawback is in the use of chemical addition for use in streams with varying compositions. Because polymer addition depends on the stream characteristics to be effective, changing stream characteristics will change the effectiveness of the chemical addition.

4. Dissolved Air Flotation

DAF is another popular technology used in many process industries for the removal of oil and suspended solids. A description of the working principles of DAF is presented in Appendix B.

a. General Applicability

DAF is used to separate suspended solids and emulsified oil from wastewater. The flotation option is particularly useful where the contaminant particulates and/or oil droplets have such low separation velocities that conventional gravity separators are ineffective. DAF equipment is typically comparable in size to gravity separation equipment. Figure C-3 (a through c) shows one type of commercial DAF system for O/W treatment.

b. Separation Efficiency

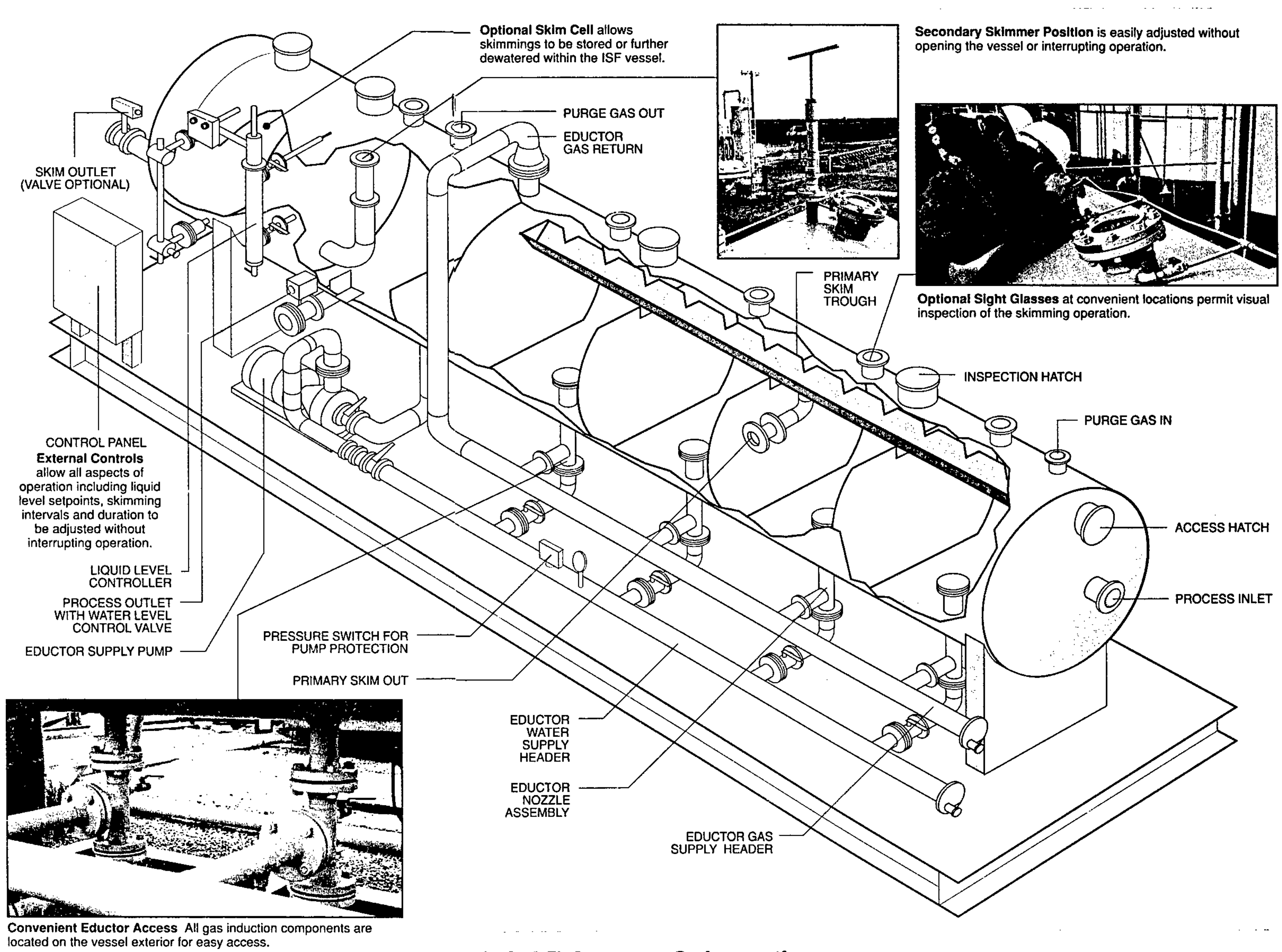
DAF equipment not only acts as conventional gravity separation equipment, but is also designed to separate emulsified oil. Removal of emulsified oil in DAF equipment is often augmented by the addition of chemical emulsion breakers, coagulants and/or flocculating agents. For satisfactory separation, 2 to 3% air by volume is usually needed. General expectations for industrial DAF devices are a

separation efficiency for free oil of 75 to 90% and emulsified oil of 10 to 40% increasing to 50 to 90% after chemical addition.[C-10 and C-11] Typical efficiencies are presented in Table C-3.

Eimco/Baker Hughes manufactures a DAF model called an ISF™ Induced Static Flotation Cell, which they claim is very resilient to system shocks.[C-12] In a study conducted by them, effluent concentrations stayed below 10 ppm for influent oil concentrations from 500 to 2,500 ppm in the inlet. When an influent oil concentration spike of 16,000 ppm was introduced, the effluent oil concentration showed a resultant spike of 30 ppm that settled back to 10 ppm as the influent concentration settled below 2,000 ppm. The system also exhibited more than 99% removal efficiency for total suspended solids. This system is recommended only for secondary separation of wastestreams with oil concentrations less than 5% and often requires additives to aid in flotation and emulsion destabilization.[C-13]

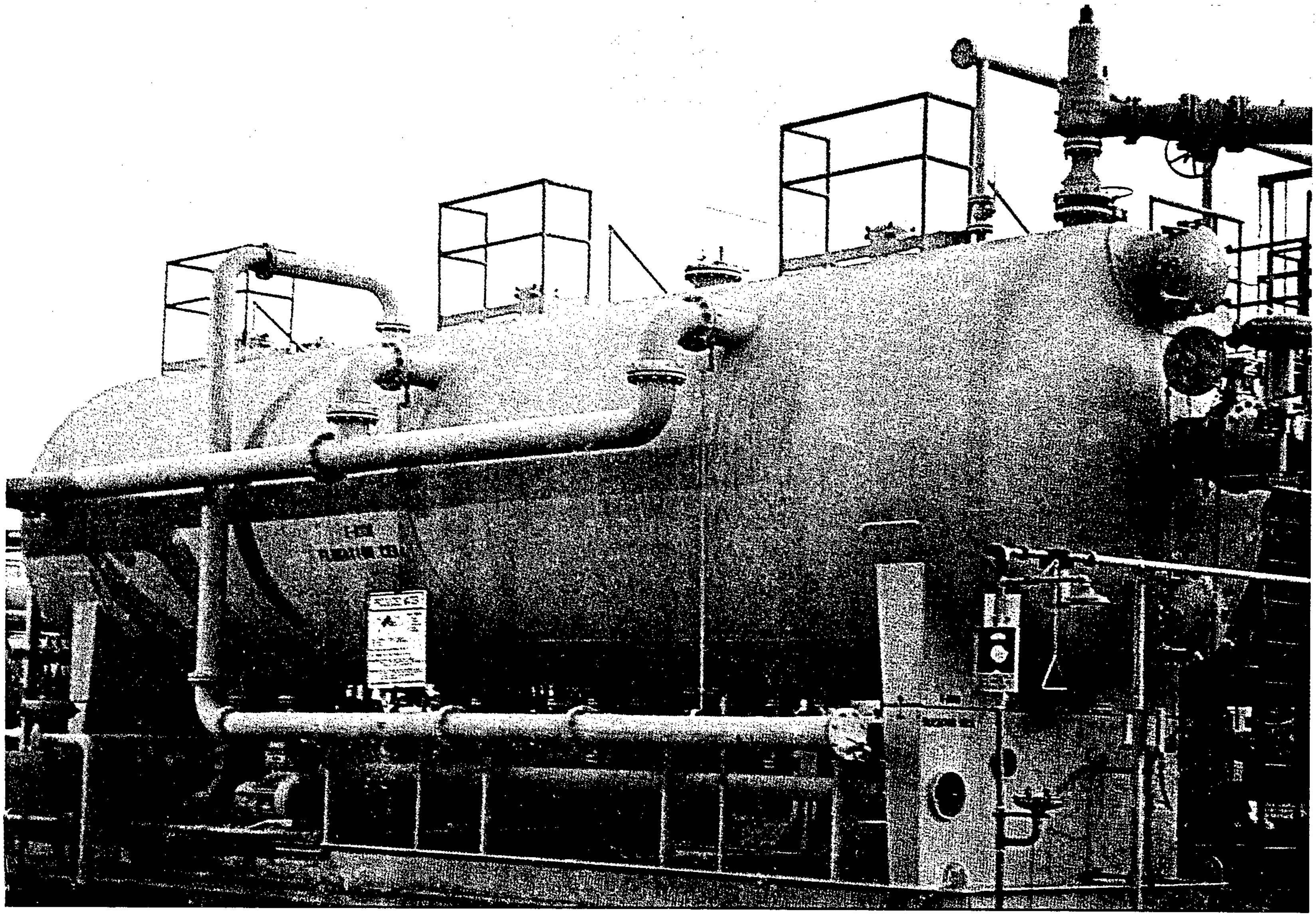
c. Operational and Design Requirements

DAF equipment is more complex than gravity separation equipment in that it requires a source of fine air bubbles. Size of a DAF system depends on the size-distribution of the emulsified oil droplets and particulate matter and the flowrate of the wastewater. Sufficient residence time must be provided within the flotation vessel for the multi-phase droplets to rise to the surface. DAF generates substantial amounts of frothy material that may require further treatment if oil recovery is desired. Although most DAF systems are contained to prevent venting of contaminated air, DAF will produce an off-gas stream that may require further treatment depending on the type of volatile contaminants in the wastewater feed. DAF equipment is frequently operated with demulsifiers and/or coagulants to enhance separation, the addition of which may require manual supervision.[C-12]



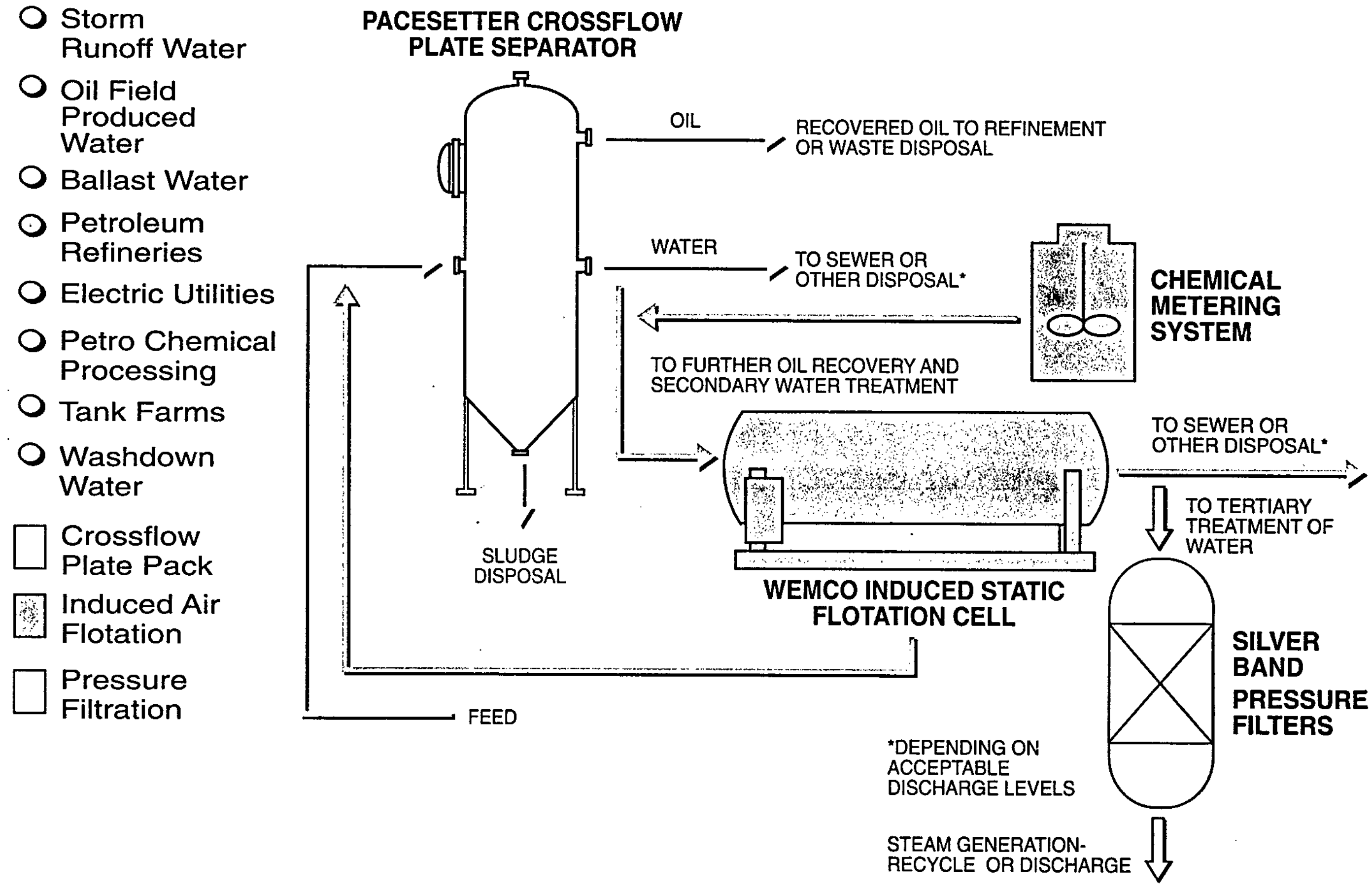
(a) DAF System Schematic.

Figure C-3. DAF System for O/W Treatment. (Eimco Process Equipment.) (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)



(b) AF System Photograph.

Figure C-3. DAF System for O/W Treatment (Continued). (Eimco Process Equipment.) (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)



(c) DAF System Incorporated into O/W Separator Train.

Figure C-3. DAF System for O/W Treatment (Concluded). (Eimco Process Equipment.) (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)

TABLE C-3. PERFORMANCE OF DISSOLVED AIR FLOTATION UNITS.[C-12]

Waste Source	Oil and Grease Concentration (mg/L)		Removal (%)
	Influent	Effluent	
Petroleum refinery	220	20	90
Hydrocarbon cracking	167	6	97
Oil tanker ballast water	35	7	80
Oil field brine water	87	7	92

As noted earlier, DAF equipment is more complex than gravity separation equipment. Commercial DAF equipment packages are designed to be well-automated and require minimum operator interference. However, the level of training required to operate these devices will be greater than that required to operate gravity separators.

d. Maintenance Requirements and Reliability

DAF equipment requires bubble-generators, pressurized tanks, special nozzles, and process control systems. Routine maintenance is likely to be more complex and frequent than for gravity separation systems. In the case of breakdown, depending on the cause of the interruption, maintenance and repair may be expensive and time consuming. Routine maintenance will help ensure that major breakdowns of the DAF do not occur. Should a major difficulty occur with the system, a trained technician, probably from the vendor, will be able to perform the maintenance.

e. Commercial Availability

DAF is a mature COTS technology and a number of manufacturers offer DAF equipment in a wide range of designs and capacities. Some of the vendors of DAF equipment include: Eimco Process Equipment, Inc./Baker Hugs; Great Lakes Environmental, Inc.; Mercer International Inc.; Wheelaborator Engineered Systems, Inc.; Davis Water and Waste Industries, Inc.; Komline-Sanderson, Inc.; Precision Environmental Systems Inc.; AFL Industries, Inc.; Seprotech Industries, Inc.; and

Metcalf and Eddy, Inc. Addresses and contact telephone numbers for these companies are listed in Table C-2.

f. Cost

DAF equipment is typically designed to handle large flowrates. Cost is a function of size and the unit must be large enough to overflow the frothy oil/air/particulate mixture. One company, Eimco Process Equipment/Baker Hughes, manufactures DAF systems with capacities ranging from 50 gpm to 5,000 gpm. The median cost of DAF systems of 100- to 500-gpm capacity is $100,000 to $200,000.[C-14]

A majority of the operating costs are due to power requirements and chemical addition, and are typically about $0.50 per 1,000 gallons of wastewater treated.[C-14]

g. Advantages

DAF is an effective COTS method for treating large quantities of oily wastewater containing emulsified oil and particulates. Air flotation tends to produce lesser quantities of sludge compared to conventional bulk demulsifying chemical addition. Many DAF technologies are resilient to concentration spikes.

h. Disadvantages

DAF requires a high capital investment and is typically limited to less than 5% contaminant oil. An off-gas stream is produced that may require treatment before discharge to the environment. DAF equipment are more complex than coalescer-based gravity separation equipment and may require constant monitoring to ensure that the air flowrate, bubble size, pH, chemical dosage, and oil skimming frequency are adjusted for optimal operation.

5. Centrifugal Separation

Centrifugal separation equipment may be broadly categorized into mechanical centrifuges and hydrocyclones. In mechanical centrifuges, the O/W mixture is centrifugally accelerated in a rotating vessel. In hydrocyclones, the O/W mixture's own inertia is used to induce centrifugal acceleration. A detailed description of the working principles of both types of centrifugal separation is presented in Appendix D.

a. General Applicability

Centrifugal separation is useful when rapid separation is required. The degree of oil removal depends on the centrifugal forces applied, and the density differential between the oil and water phases.

Centrifugal separation is very effective in separating mechanically dispersed and free oils (non-emulsified oils) from water. While centrifugal systems are capable of separating free-oil, they are primarily used to remove mechanically dispersed oil. Because surfactants reduce the effective density differential between the water and oil, most centrifuge manufacturers involved with wastewater treatment offer systems with an emulsion breaking stage prior to centrifugal separation. Figure C-4 (a through c) shows a commercial mechanical centrifugal separation system for O/W treatment systems. Figure C-4 (d) is the schematic for a commercial hydrocyclone application for O/W treatment.

Common types of mechanical centrifuges are the disk and bowl types. The choice of either of these types depends on the application. However, disk type centrifuges are more commonly used in O/W treatment systems.

Although some designs allow a three-phase separation with oil leaving the top of the centrifuge, water leaving the middle orifice and water and particulate exiting from the bottom, the performance of mechanical centrifuges is greatly affected by the solids content of the wastestream. The performance of O/W separator hydrocyclones is also reduced by the presence of solids in the wastestream. Hydrocyclones are less expensive than equivalent mechanical centrifugal systems. However, mechanical centrifuges can be operated at very high velocities and can produce very high g-forces enabling faster separation and filtration of oil droplets in the submicron and nanometer range. Centrifugal treatment systems are smaller than gravity separators with comparable treatment capacities.

b. Separation Efficiency

Mechanical centrifuges can achieve separation efficiencies equal to or better than gravity separators in a shorter period of time. However, if the particulate and/or oils loading is greater than the design specifications for the centrifuge, the

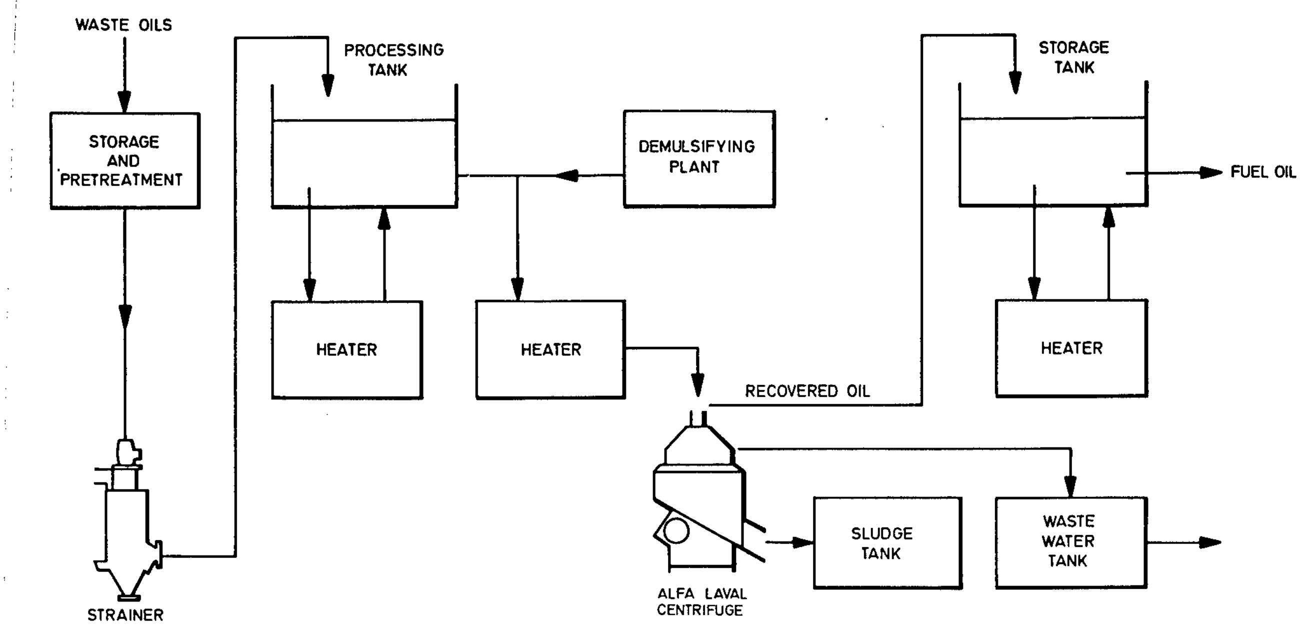
performance can be seriously degraded. A disk centrifuge, receiving a wastestream that has been pretreated to break emulsions, can deliver an aqueous stream containing 25 to 100 ppmv oil.[C-15]

Hydrocyclones can also achieve very low effluent concentrations of non-emulsified oil. Table C-4 shows effluent concentrations achieved in two projects which used hydrocyclones to separate free oil and water.

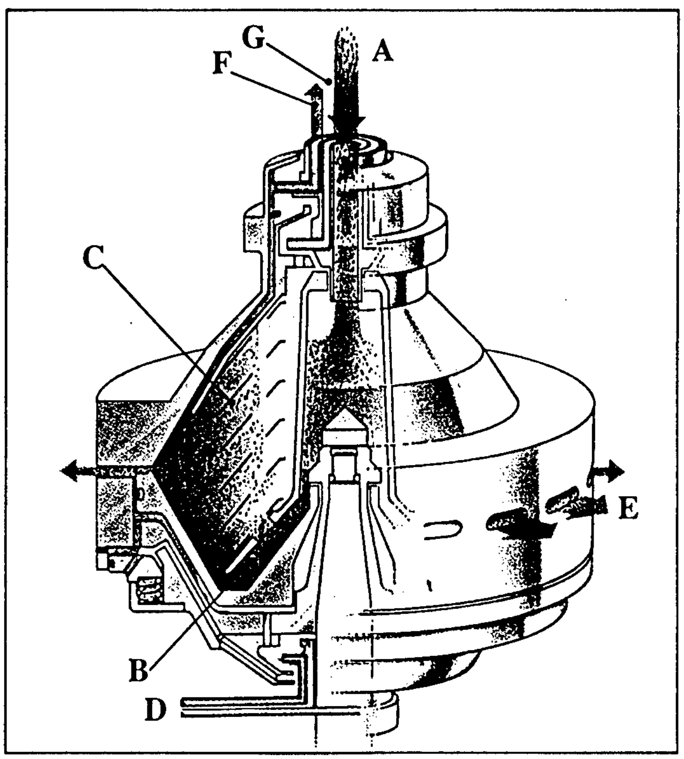
A study with Young, et al.[C-16] using a Colman-Thew hydrocyclone showed a separation efficiency of 95% for an oil phase with a 0.85 specific gravity. The efficiency was reduced to less than 80% when the oil phase had a specific gravity of 0.96, even for oil droplets up to 60 μm in diameter. Because hydrocyclones and centrifuges use density differences to separate the phases, separation efficiency is reduced when surfactants are added The surfactant reduces the effective density differential between the oil and water. For mechanical centrifuges and hydrocyclones, emulsified oil can be removed by pretreating the influent with emulsion breakers.

c. Operational and Design Requirements

Mechanical centrifugal systems require external power to operate. The size and type of mechanical centrifuge used depends on the flowrate, nature of the wastestream such as oil density, particulate concentration and size, and separation level desired. Depending on the size of the units, noise reduction equipment may be necessary.

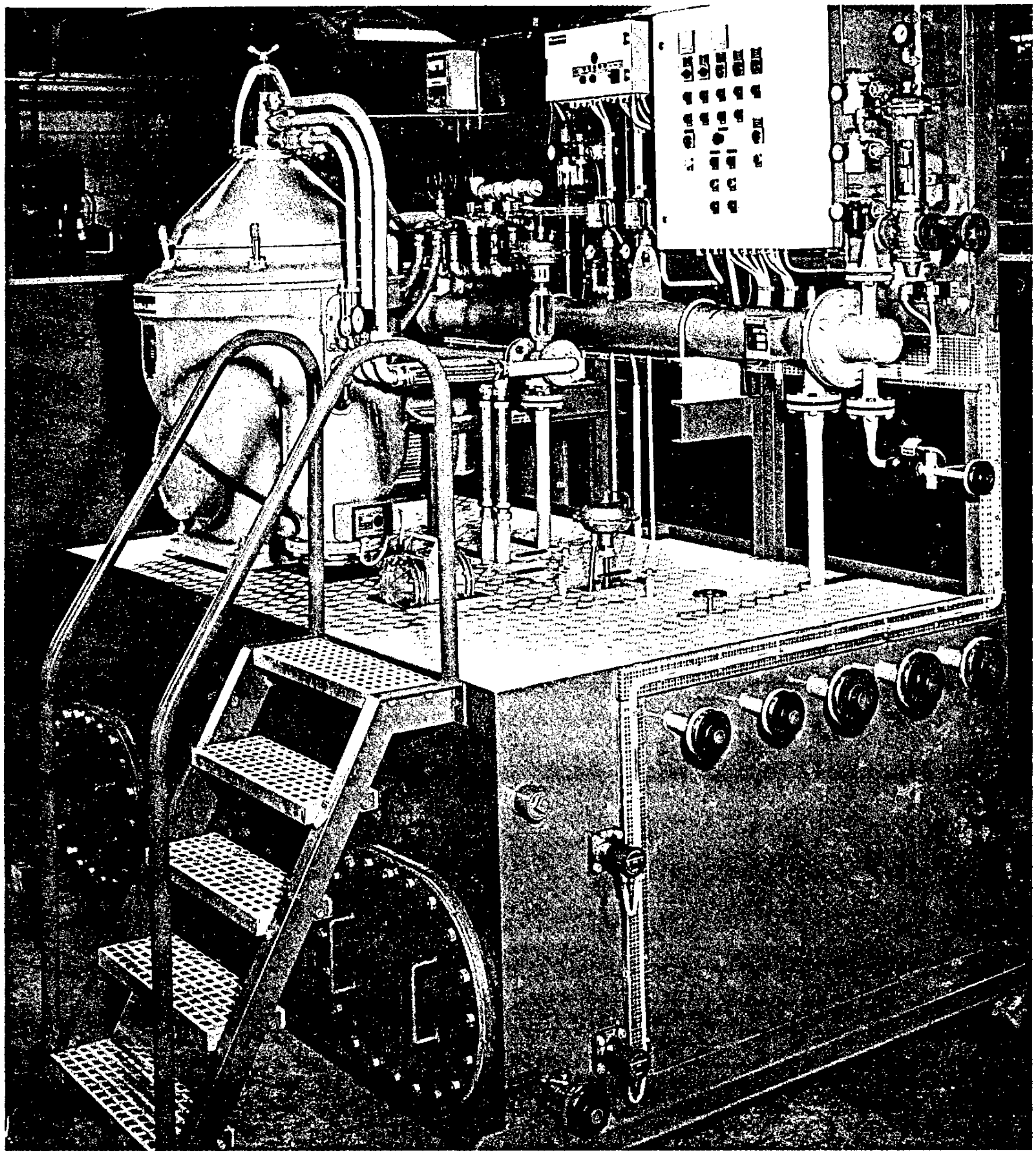


(a) System Flowsheet. (Alfa Laval).



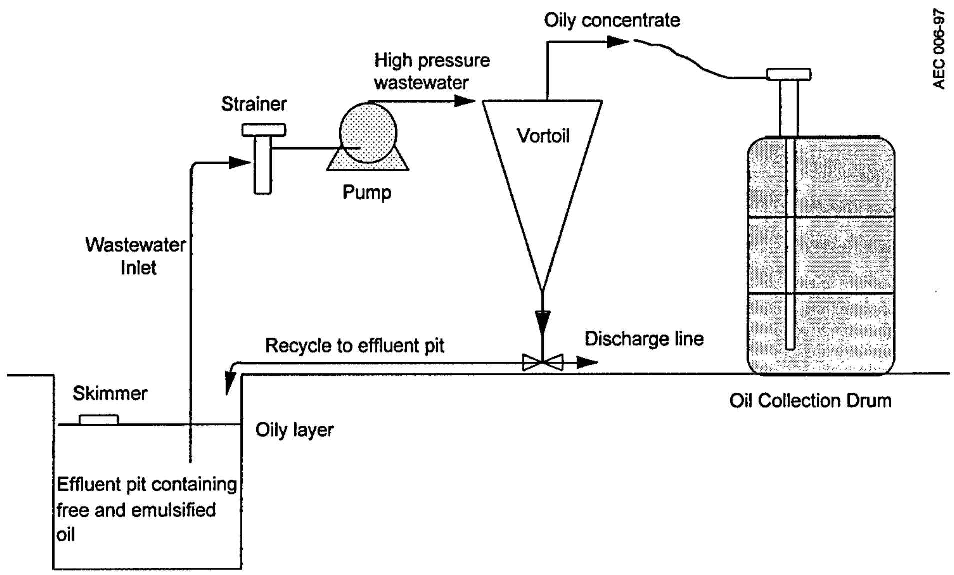
(b) Disk Type Centrifuge Schematic. (Alfa Laval.)

Figure C-4. Commercial Mechanical Centrifugal Separation System for O/W Treatment Systems. (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)



(c) O/W Treatment System Photograph. (Alfa Laval).

Figure C-4. Commercial Mechanical Centrifugal Separation System for O/W Treatment Systems (Continued). (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)



(d) Hydrocyclone Based O/W Treatment System. (VORTOIL Separation Systems.)

Figure C-4. Commercial Mechanical Centrifugal Separation System for O/W Treatment Systems (Concluded). (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)

TABLE C-4. PETROLEUM FACILITIES PROCESS WATER TREATMENT RESULTS USING HYDROCYCLONES.(C-17)

Project Location	Inlet Pressure (psi)	Flowrate (barrels/day)	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)
Louisiana	920	6,300	450 to 2,000	<20
Indonesia	60 to 160	300 to 1,600	20 to 1,000	0.5 to 15

Mechanical centrifuges are complex machines with a number or moving parts and will require substantial training and education. The operator will need knowledge of how to clean and balance the centrifuge when small disturbances take place, but the centrifuge will probably require an extensively trained technician supplied by the vendor or some other authority, to perform more extensive maintenance and repairs.

In general, hydrocyclones are simple devices compared to mechanical centrifuges and consist of no moving parts. The centrifugal force is generated by the tangential inlet velocity of the wastestream. Key parameters of O/W density differential, throughput, and ratio of oil to water in the mixture are the most important considerations in the design of hydrocyclones (see Appendix B). Typically a pump is required to generate a sufficient dynamic head or a high-pressure air supply at approximately 100 psi. The level of operator training will be less than that required for mechanical centrifuges and more than that required for simple gravity separators.

d. Maintenance Requirements and Reliability

When operated within design specifications, mechanical centrifuges are known to provide excellent results. Due to the fact that they are complex equipment, routine maintenance is expected to be frequent and in the case of breakdown of the system, repair can prove to be very expensive. Hydrocyclones, in general, are robust devices, and maintenance as well as operation is expected to be less complex than that for mechanical centrifuges.

e. Commercial Availability

A number of manufacturers offer mechanical centrifuges and oily wastewater treatment systems using centrifuges. Some of the established vendors include: Alfa Laval Separation AB; Dorr-Oliver, Inc.; CINC; CARR Separations; Bird Machine Co.; and Ingersoll Rand Co. Addresses and contact telephone numbers for these companies are listed in Table C-2. Mechanical centrifuge systems offered by the above companies are designed to handle flowrates ranging from 0.5 to 500 gpm.

VORTOIL Separation Systems, a subsidiary of Baker Hughes Process Systems, manufactures portable hydrocyclone separation equipment. The portable hydrocyclone can process 5 to 10 gpm, and an underflow recycle feature exists to achieve very high degrees of separation. Conventional hydrocyclones are used in the refinery and petroleum industry to separate oily sludges. Manufacturers of conventional hydrocyclones include: Lakos Laval Corp.; Dorr-Oliver, Inc.; and Yarney Water Management Systems, Inc.

f. Cost

Mechanical centrifuges are relatively expensive. A cost effective strategy would be the removal of free oil using a simple gravity separator system followed by a centrifugal system to remove the mechanically dispersed oil thereby reducing the flowrate through the centrifuge. The purchase price of a 2- to 3-gpm Alfa Laval O/W treatment system (see Figure C-4[c]) is approximately $50,000 to $60,000. The purchase price of a 200 gpm treatment system is about $175,000 to $200,000. The installed cost, which includes holding tanks for demulsification and solids accumulation is expected to be approximately 15% of the purchase price. Another company, CINC, manufactures centrifuges under license from the U.S. Department of Energy (DOE). CINC's line of low-g (200 to 300 g) and low-rpm (1,000 to 3,000 rpm) centrifuges are claimed to be suitable for O/W separation, require minimal maintenance, and are manufactured to handle flowrates between 0.5 and 200 gpm, with a corresponding price range of $6,000 to $200,000. The majority of the operating costs for the above systems are due to the power demand and chemicals for demulsification. Operating costs for the Alfa Laval system are expected to be between $40 and $60 per thousand gallons of wastewater treated.

The VORTOIL hydrocyclone system (Model PK-PN) costs about $25,000 and can treat up to 10 gpm of wastewater. The investment for the Louisiana project cited in Table C-4 was $51,000.[C-16] Installation costs are expected to be minimal. The majority of the operating costs for the hydrocyclone system are also expected to be due to pumping power demands and demulsification chemicals.

g. Advantages

Mechanical centrifuges are efficient for rapid separation of oil from water. They are suitable as retrofit systems, are relatively small in size, and are suitable for transportation to different locations.

Hydrocyclones are also efficient for rapid separation of oil and water. They have the further advantage of having no moving parts, being more compact, effectively portable, and less expensive than mechanical centrifuges. Both

mechanical centrifuges and hydrocyclones are capable of achieving very low effluent oil and grease concentrations.

Although both hydrocyclones and centrifuges are sensitive to particulate loading, both systems are available in models designed to handle three phase separation. In these models, the system would be capable of handling solids loading and separating the sludge into an oily phase, a clean water phase, and a wet particulate phase.

h. Disadvantages

Mechanical centrifuge systems are complex and expensive. Both mechanical centrifuges and hydrocyclones are not capable of removing emulsified oils and require emulsion breaking systems to treat the wastewater before entry. Centrifugal systems are sensitive to solids and large fluctuations in the oil concentration of the wastestream. Both mechanical centrifuges and hydrocyclones require careful and thorough design as they are sensitive to changes in composition and flowrate. Operating these devices at flowrates greater than they were designed to handle, or significant variations in the influent oil concentration adversely offset the efficiency. Centrifugal systems tend to be very noisy and may require extensive equipment to reduce the noise levels by as much as 10 dB.[C-18]

6. Air-Sparged Hydrocyclones

a. General Applicability

ASH is an emerging technology that incorporates the principles of hydrocyclones and DAF. The feedwater enters through a standard cyclone opening and passes through a porous tube while developing an angular component of velocity which affects centrifugal separation. Pressurized air is passed into the porous tube introducing air bubbles to the system. The air bubbles attach to the oil droplets and suspended particles to increase their effective density and encourage separation. The lighter phase (oil and suspended particles) travel to the core of the cyclone and up to the center to an overflow tube. Water exits as underflow discharge. A detailed description of the working principles of ASH is presented in Appendix D.

b. Separation Efficiency

ASH technology is applicable to O/W separation and has been demonstrated on a pilot-scale at various sites. In one typical ASH application, contaminated water flowrates were 100 to 400 gpm/ft^3 of ASH unit volume, with an overflow to underflow opening diameter ratio between 0.69 and 0.79 and an air-flow-to-water-flow ratio ranging from 2.4 to 6.0.[C-19] There have been several pilot-scale demonstrations of ASH technology in the AF. Table C-5 summarizes the results of some of those demonstrations. The ASH system which operated at Tinker AFB was estimated to have a power consumption cost of 6.3 kWh per 1,000 gallons and a reagent consumption cost of $0.40 to $1.10 per 1,000 gallons.[C-19]

c. Operational Complexity and Design Requirements

Operation and design requirements for ASH are similar to hydrocyclones. ASH must be designed with a clear knowledge of the expected stream flowrate and composition. For this reason, detailed stream analysis and pilot-scale treatment data may be useful. In addition to the requirements of a standard hydrocyclone, ASH requires compressed air for the generation of bubbles.

ASH technology is not an established technology in the O/W separator industry and may require further evaluation before being commercialized on a large scale. It has the advantage of combining two efficient separation mechanisms and may become an even more efficient separation process than either DAF or hydrocyclone. Information on cost, reliability and maintenance, and operational considerations is not available, as ASH technology is still in the developmental stages.

7. Depth Filtration

a. General Applicability

Depth filtration is a mature COTS technology, and is commonly used in the wastewater treatment industry. It is most applicable to wastewater with low oil and low suspended solids concentrations being frequently used as a final polishing step. Depth filtration uses a filtration medium to separate oil from water. The filtering medium usually consists of an oleophilic/hydrophobic substrate on which the oil droplets coalesce.

TABLE C-5. RESULTS FROM PILOT-SCALE DEMONSTRATION OF ASH[a] TECHNOLOGY.(C-19)

System	Flowrate (gpm)	Feed Pressure (psi)	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Surfactant Additions
Wastewater (Tinker AFB)	20 to 30	N.A.[b]	17	14	None
Wastewater (Tinker AFB)	20 to 30	N.A.	31 to 5,500	0 to 150	Polyelectrolyte and surfactants
Oil and aqueous film forming foam (AFFF)	N.A.	N.A.	500 (oil) 1,000	200 (oil) 250	Not mentioned
Wastewater (F-15 washrack)	~22	10	1,264	30	5 mg/L polyelectrolyte
Wastewater (F-15 washrack)	~22	10	9,743	80	10 mg/L polyelectrolyte 15 mg/L surfactant

[a] = Single and two-stage ASH treatments were used.(C-19)
[b]N.A. = Not available.

Depth filtration of industrial wastewater is usually carried out in filters containing fibrous or granular media. Figure C-5 (a through c) shows industrial depth filtration systems. The size of the depth filtration unit depends on the quantity of wastewater treated. Industrial depth filtration equipment are available for handling flowrates ranging from 10 to 1,000 gpm of wastewater. Typical depth filters include fibrous media made of: stainless steel, cotton, dynel, fiberglass, peat and shells of various types of nuts (walnut, pecan, etc.) and organoclays that are a quaternary amine-modified granular bentonite clay or zeolite.

b. Separation Efficiency

In one study at Andrews AFB, Battelle researchers demonstrated excellent separation efficiencies using a depth filtration system.(C-20) In this study, the

wastewater had an oil concentration of 1,000 ppm and was first treated in a settling tank. The effluent from the settling tank, containing oil between 100 and 200 ppm, was treated by passing it through a drum containing 200 lb of organoclay. The wastewater leaving the drum had an average oil concentration of 5 ppm.

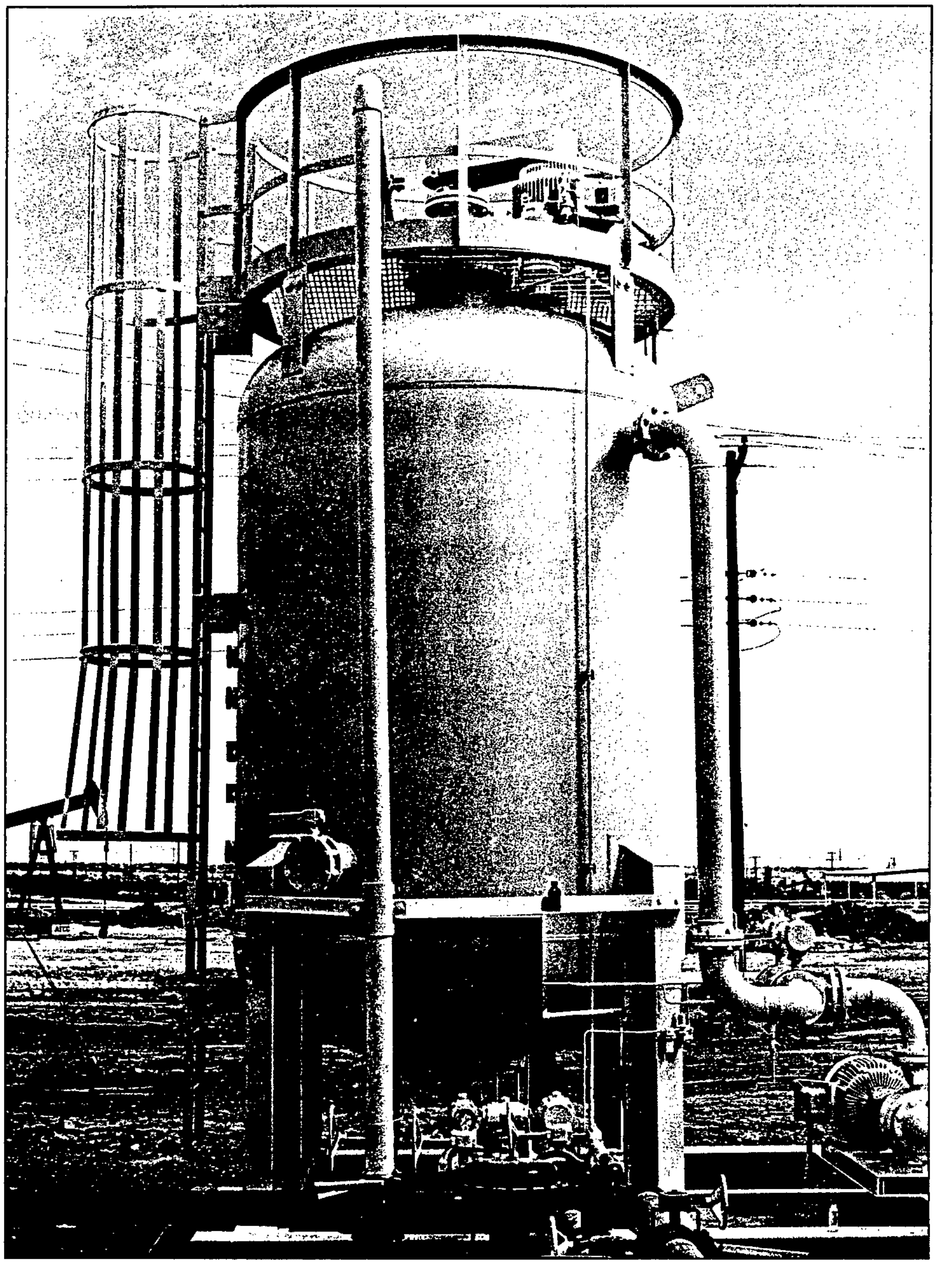
BoniFibers H™ is a commercial synthetic fine-fiber medium, composed of carbon and hydrogen, manufactured by BPM, Inc.[C-20] The vendor claims that the fiber can typically treat water to contain less than 10 mg/L oil, and that 1 lb of BoniFibers H™ can capture 25 lb of oil. These results were for a flowrate of about 3 gpm/ft of bed depth and about 4 gpm/ft^2 of bed area.

A patented oil-absorbing material by Kuwahara, et al., is made from a natural fiber that contains pulp or 5 to 50% of meltable fibers.[C-20] The hydrophobic agent in this material is a fatty acid-based polymer mixed with oxidizing paraffin and a protective gel. This material appears to be a viable medium for removing oil from water.

Organoclays have the advantage that they are commonly used to remove heavy metals from the wastewater stream and are efficient even for streams of varying composition and flowrate.

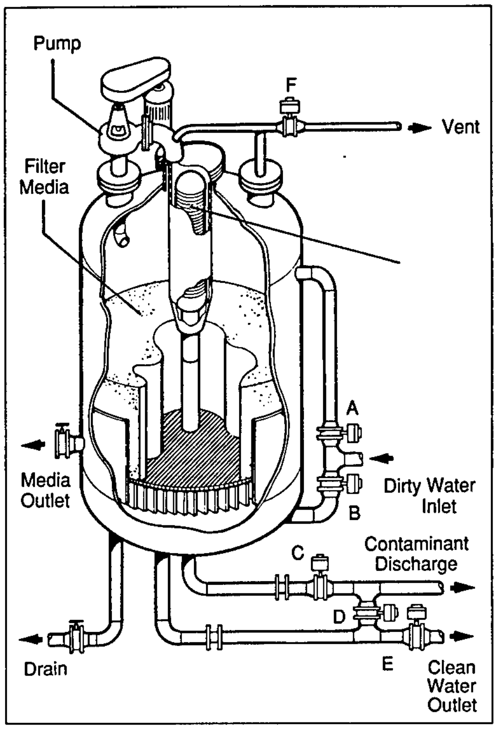
c. Operational and Design Requirements

Depth filtration equipment are generally simple devices. Utility, labor, and personnel training requirements are nominal. A typical small depth filtration system has wastewater pumped into packing media in a 55-gal drum with effluent water drawn from the bottom (Figure C-5[c]). There are others, like the Wemco Silver Band® filter shown in Figure C-5 (a and b) that operate on larger capacities and are more complex devices. The size of depth filtration equipment is determined by the amount of filter media required to treat a given effluent stream. The size is optimized by maximizing the wastewater flux rate through the filter bed. Some depth filtration media can be regenerated, but organoclays are once-through devices and spent clay must be disposed. Although some clays can be incinerated depending on the heating value of the adsorbed oil, most clays are landfilled at this time.

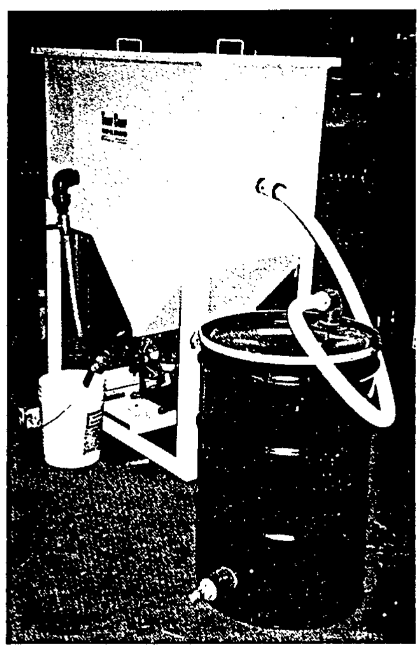


(a) Photograph of Industrial Depth-Filter Based O/W Treatment System. (Eimco Process Equipment.)

Figure C-5. Industrial Depth Filtration Systems. (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)



(b) Schematic of (a).



(c) Biomin EC-2002 O/W Separation Recycling System Using Organically Modified Clay.

Figure C-5. Industrial Depth Filtration Systems (Concluded). (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)

d. Maintenance Requirements and Reliability

Depth filtration processes are robust when operated within their design specifications. A critical maintenance item for most depth filtration applications is regeneration/replacement of the filter media. Some fibrous media can be regenerated by cleaning with steam or fresh water. Organoclays are generally non-regenerable and must be disposed. The life-cycle of the filter media depends on the application and particulate matter will reduce the life expectancy of the media.

e. Commercial Availability

Depth filtration is a mature COTS technology and is available through many vendors. Vendors of depth filtration systems include: Eimco Process Equipment; BPM, Inc.; American Felt and Filter Co.; Industrial Filters Co.; Great Lakes Environmental, Inc.; Biomin, Inc.; Carbtrol Corp.; and Sher-Fran Corp. The latter three companies deal with organoclay systems. Addresses and contact telephone numbers for these companies are listed in Table C-2.

f. Costs

Depth filtration systems vary widely in price depending on the filtration medium used and the application. Small size treatment systems, such as that offered by BPM Inc., containing about 15 lb of the fibrous media cost about $400. Biomin, Inc., sells an organoclay product (EC-100) that is being used by a number of water treatment facilities for oil and other hydrocarbon (e.g., benzene, toluene, ethylbenzene, xylenes [BTEX]) removal at a cost of $1.40/lb. The usage rate of the clay depends on the concentration of the contaminants and the flowrate. Disposal costs for the Biomin system are estimated as $0.90/lb for labor to remove spent clay and $0.25/lb to dispose of the clay).[C-21] In the case of organoclays and certain fibrous filters that are not regenerable, disposal costs as a hazardous waste may be incurred.

Larger systems, similar to that shown in Figure C-5, that are capable of handling about 100 gpm of wastewater and containing pecan/walnut shell as the filter media cost about $150,000 (Eimco Process Equipment). This cost includes an automated filter-bed regeneration system which works by fluidizing, mixing and draining the bed to recover approximately 75% of original capacity. The backwash water can be

returned to the separator inlet, but this concentrated wastewater is usually disposed. A majority of the operating costs for these systems are due to the power requirements and replenishment/replacement of the filter media.

g. Advantages

Depth filtration systems can achieve low concentrations of oil in the effluent and are well suited for polishing wastewater already treated to remove free oil (e.g., effluent from settling tanks). Depth filtration systems are available in compact portable sizes, and can be transported to various locations to be used as polishing systems. Depth filtration systems are relatively inexpensive both for capital and operating costs.

h. Disadvantages

Depth filtration systems are not well suited to handle primary waste streams containing high concentrations of particulate matter and oil. Treatability studies may have to be performed to determine the appropriate filter media as media are not universal to all types of oil. In the case when the filtering media has to be replaced, disposal and handling costs may be considerable.

8. Membrane Filtration

a. General Applicability

Membrane separation technology is generally a mature technology in the liquid/liquid separation industry. However, in areas such as oily wastewater treatment, where it can remove emulsified oils, its application has been limited and is still considered an emerging technology. Membrane filtration systems are used when the quality of the effluent water has to achieve high standards, for example, for reuse in process streams, laboratories, and potable water aboard ships. At Mountain Home AFB, a membrane unit is used to recycle aircraft wash water from the corrosion control hangar. Membrane separation systems are best applicable to treat relatively small quantities of wastewater, 200 to 1,800 gpd (0.14 to 1.25 gpm) to achieve high clean-up standards. Commercially available membrane separation systems are not capable of cost effectively treating flows that can be achieved by the methods discussed in the previous sections.

Membranes may be made of polymeric materials such as cellulose acetate, polysulfone, polyacrylic, and polyamide, or inorganic materials such as x-alumina, zirconium oxide, and titanium oxide. A detailed description of the working principles of membrane technology is presented in Appendix D. Membrane filtration processes are classified according to pore sizes: microfiltration (MF) membranes have nominal pore sizes between 0.2 and 10 μm, and ultrafiltration (UF) membranes have nominal pore sizes between 0.01 and 0.2 μm.

b. Separation Efficiency

Membrane separation units are very efficient in removing emulsified and non-emulsified oil droplets. The separation limits for membranes are not dependent on influent oil concentrations. Higher concentrations may foul the membrane and limit the operating time of the membrane, but the effluent will be filtered to the same degree. Very high concentrations of oil and grease can be reduced to concentrations below 10 mg/L depending on the type of membrane used.

A study by Bhatacharya, et al., examined the performance of a membrane system in processing systems of oil and water in the presence of detergents.[C-22] The presence of detergents and the mixing of the system lead to the formation of stable emulsions in the influent wastestream. Even in systems with up to 200 mg/L of nonionic surfactants, membrane separation was able to reduce permeate oil concentrations consistently below 10 mg/L from influent concentrations of 100 to 5,000 mg/L and showed performance independent of feed concentration and specific gravity of the oil phase. The membrane used was a noncellulosic membrane with a maximum pore size of 0.005 μm. The membrane could be used in the pH range of 2 to 13 and at temperatures up to 60°C. For all systems there was a decline in flux with use, but a steady-state flux was generally reached. The flux across the membrane decreased as detergent concentrations increased, due to micelle formation and physical adsorption of the surfactant to the membrane. The original flux with a fresh membrane was regained by flushing with distilled water and cleaning with a weak chlorine solution.

A recent study by Norris and Quatrini examined the removal efficiencies of oil from water in petroleum operations.[C-23] The process streams did not contain chemically emulsified oil, but did contain considerable amounts of suspended solids and salt concentrations. Oil was effectively removed using inside-out and outside-in membranes with concentrations consistently reduced from 100 to 1,200 mg/L to less than 5 mg/L. The fouling of the membranes was considerable due to the deposition of solids, mineral scale, and oil blockage. The membranes were effectively cleaned at intervals of a few hundred hours.

A study by Lipp, et al., examined the performance of a series of polymeric membranes in separating O/W emulsions with emphasis on the effects of oil droplet size and regenerative capacity.[C-24] They found that larger droplets were formed at the membrane, indicating that membrane filtration leads to coalescence at the membrane feed solution interface. Oil rejection by the membranes was independent of the influent oil concentration and membrane type and was greater than 99.9%, corresponding to effluent concentrations of less than 10 mg/L. When regenerating the membranes the capacity of the cellulosic membrane was almost completely recovered (93%) while the polysulfone was unable to be regenerated at all (0.5%). The degree of fouling was also related to the influent oil concentration. The flux varied linearly with the oil concentration up to a value of 10%.

Chen, et al., investigated the use of ceramic membrane filtration elements in the recycling of aqueous alkaline cleaning solutions.[C-25] The solutions processed contained a mixture of oils and surfactants. The study investigated membranes with pore sizes of 0.05, 0.2, and 0.8 μm. All of the membranes effectively removed oil and grease concentrations from influents as high as 25,000 mg/L to values below detection limits (detection limits were different for each oil and ranged from 42 to 160 mg/L). All of the membranes experienced some degree of permeability reduction with use, but the 0.05 μm element exhibited less flow reduction and easier regeneration. The membranes were cleaned with a caustic rinse to remove oily substances, an acid rinse to dissolve inorganic foulness, a detergent solution, and a dilute solution of a household bleaching agent. The study concluded that the 0.05 μm

membrane could most reliably and continuously remove oil and grease from a water solution, even when the oil and grease were emulsified. The process has been scaled up to a pilot-scale installation and will be demonstrated using a full-scale system.

c. Operational and Design Requirements

Polymeric membranes are typically constrained to operating between 0° and 80°C. Polymeric membranes may be easily fouled by oil and grease and are often difficult to regenerate. Cellulosic membranes operate in an acidic environment and are constrained to pHs between 2.5 and 7. Ceramic membranes have better physical integrity, are resistant to a wide range of temperatures and pH, and are capable of filtering solids since these membranes can be regenerated using acids or bases.

A successful membrane separation system requires frequent monitoring and the use of flux enhancement measures such as backpulsing, fast flushing, and chemical pretreatment to keep it from fouling. Frequent regeneration of ceramic membranes or disposal of non-regenerable membranes may be required if the influent has high loadings of solids. Overall, membrane separation systems are high maintenance items in comparison to the other O/W separation methods and will require greater operator training and attention.

d. Maintenance

Fouling of membrane systems is inevitable making membrane cleaning/replacement the key maintenance item. Membrane systems are less robust than mechanical separation methods, and require more frequent routine maintenance.

e. Commercial Availability

Membrane separation is a mature COTS technology, but still emerging in its application to O/W separation, with applications in a wide variety of industries. A partial list of companies that offer membrane technologies applicable to O/W separation include: MSC Liquid Filtration Corp.; RGF Environmental Systems, Inc.; Seprotech Systems, Inc.; U.S. Filter; Osmonics, Inc.; CUNO Separation Systems, Inc.;

Zenon; Compliance Systems, Inc.; Membrex; and Hyde Products, Inc. Addresses and contact telephone numbers for these companies are listed in Table C-2.

f. Cost

Membrane separation systems are generally expensive. RGF Environmental Systems offers a 1,000-gpd membrane system (Model CT-1000) for O/W separation at a purchase price of $13,000. MSC Liquid Filtration Corp. offers microfiltration systems installed costs for which are estimated to be $18,000 for a 200-gpd system, and $45,000 for a 1,800-gpd system. The annual operating costs for these systems are approximately $20 to $30 per 1,000 gallons of water treated. While capital costs for membrane systems do not appear to be significantly larger than other technologies, membrane systems require frequent replacement of the membrane and have high operating costs.

g. Advantages

Membrane separation is a good option when very high standards of discharge water are required. They show flexibility in treating a wide range of inlet concentrations and are not dependent on density differential between the oil and water. Membrane separation systems require little chemical addition or other pretreatment for demulsification and can remove particulate and oil from water to very low concentrations. Commercial membrane separation systems are relatively compact and self-sufficient units, and are ideal for transporting to different locations.

h. Disadvantages

There are tradeoffs with the ability of membranes to filter to a discharge standard largely independently of the influent stream composition. The most pronounced being the proportional relationship between influent oil concentration or particulate loading and the speed of membrane failure due to fouling. Membrane separation systems are expensive, high maintenance items, and do not have an established history of use in the treatment of oily wastewater. Frequent monitoring and maintenance of membrane technology is usually necessary to keep the membrane unobstructed. Membrane systems experience reduced efficiency with the presence of solids in the influent wastestreams which block flow through the membrane. Particulate

and heavy oil concentration can cause the membrane to foul; this is the most frequently encountered problem with membranes.

9. Electrical Field Separation

Electrical field separation has been widely used in mining related industries. It is an emerging technology for O/W separation. Electroacoustic separators and nested-fiber filter separators are two types of emerging electrical field separation technologies with potential applications to O/W separation described in Appendix D. Further testing and development of these products may be required before they are commercially available for O/W separation. A major factor in the cost of operating these technologies will be due to the electrical power requirements. Battelle has demonstrated the application of electrically charged nested-fiber filters for use in O/W separation. However, the technology has not yet been commercialized.

10. Biotreatment

a. General Applicability

Biotreatment can be applied to a wide variety of organic waste streams and can operate aerobically, with oxygen, or anaerobically, without oxygen. Anaerobic biotreatment would not be suitable for treating oil and grease in wastewater. While biotreatment has been widely applied to treat sanitary and industrial wastewater to remove toxic organics, it is an emerging technology for O/W separation. Treatment systems have been applied to wastewater streams from a wide range of sources including power plants, refineries, machining, and municipal gas production. Several systems are compact enough to be fairly mobile allowing them to be shifted between different waste streams. Biological treatment is generally applicable to streams which are not contaminated with metals or other substances toxic to bacteria, although some bacteria have shown an ability to survive and even remove spikes of toxic inorganics without adversely affecting performance of the media.[C-26]

b. Separation Efficiency

Biotreatment has the potential to operate at high efficiencies resulting in an effluent with oil and grease levels below discharge limits. One commercial system (manufactured by EFX; see Table C-2) claims to remove organic

constituents including oil and grease to less than 10 ppm. Some systems can also remove dissolved and suspended solids. Longer residence times generally allow the bacteria to more completely digest the organic matter. Efficiency depends on many factors some of which are the composition of the stream, temperature, pH, and biochemical oxygen demand (BOD).

Results from one full-scale pilot-test of a granular, activated carbon/fluidized-bed reactor (GAC-FBR), manufactured by EFX Systems, Inc., are presented in Table C-6. Two reactors were acting in series to treat produced water from petroleum extraction activities. The influent had a high concentration of VOC, oil, and grease. The system operated at more than 95% removal efficiency for all but the COD. Results are presented in Table C-6.

TABLE C-6. RESULTS FROM A FIELD EVALUATION OF A FULL-SCALE GAC-FBR TREATING PRODUCED WATERS IN THE WESTERN UNITED STATES.[(C-25)]

Parameter	Influent	Effluent	Removal, %
Benzene (μg/L)	1.460	<1	>99.9
TVH[a] (μg/L)	63,500	2,620	95.9
Oil and grease (mg/L)	75	3	95.8
Volatile fatty acids (mg/L)	120	<2	>98
COD[b] (mg/L)	510	84	83.5

[a]TVH = Total volatile hydrocarbons.

[b]COD = Chemical oxygen demand.

Unlike most biodegradation facilities, where microbes are carefully supported, exploratory tests were performed at Luke AFB, Arizona, where they periodically injected the influent stream of their industrial wastewater treatment plant (IWTP) with microbes and nutrients. Periodic injection of nutrients and microbes was required, as the microbes were simply allowed to flow out with the wastewater with no fixed media to support them in the gravity type O/W separator. The intention of the informal tests were to observe the effects of the microbes on destruction of phenol in

the wastestream. The personnel at Luke AFB noted a preliminary beneficial side effect from the biotreatment — previously visible oil and grease agglomerates were no longer detectable after the introduction of the microbes. No effort was made to control pH, temperature or other parameters, which suggests that microbes might be able to live under less than "ideal" circumstances.[C-27]

c. Operational and Design Requirements

Biotreatment systems vary in their requirements. In general, a pH between 5 and 9, preferably between 6 and 8, must be maintained. Most conventional biodegradation units operate in a temperature range of 10° to 30°C depending on the microbes used. All systems require treatment of the sludge which forms at varying rates for different systems. Nutrients such as phosphorous and nitrogen are often added to sustain microbial growth. Nutrient requirements for microbial activity are often expressed in terms of BOD-nitrogen-phosphorus ratio. Wastes having a ratio of 100:5:1 are usually considered to have an adequate nutritional basis.[C-28]

Biotreatment systems vary in complexity, but most systems are relatively simple. The support system required to ensure adequate operating conditions for the microorganisms is the key component of this technology. The sludge which is generated is usually biologically stable and non-odorous with excellent dewatering capabilities.

d. Maintenance Requirements and Reliability

Under ideal operating conditions (specific to each system) biotreatment systems can be self-sufficient requiring little maintenance. Minimal maintenance is required with some systems requiring only weekly checks of effluent concentrations. An aquatic balance of pH, temperature, critical mass of bacteria and food source, both organics/oils and nutrients, must be maintained. Many systems can survive under starvation conditions for some time although the bacteria are most likely to survive and operate efficiently with constant use.

e. **Commercial Availability**

EFX Systems, Inc., has an activated carbon based fluidized bed for aerobic treatment of oily wastewater available in 10- to 200-gpm capacities. These systems require minimal maintenance and the occasional addition of small amounts of nitrogen and phosphate. ARCADIS Geraghty & Miller has a pilot-scale bioreactor using a fixed bacterial film capable of operating under aerobic or anaerobic conditions and is available for demonstration in treatability studies.

f. **Cost**

The EFX system is available in 30-gpm capacity for \$100,000 ±20%, depending on process requirements. Microbes are more active at higher temperatures (about 30°C). The increased efficiency at the higher temperatures helps to offset the cost of heating. Treatment for offgases, particularly from aerobic biotreatment units, may be necessary. Although some units have high installation costs, operational and maintenance costs for well designed units are very low. Of the aerobic processes, aerated lagoons and activated sludge have moderate installation costs, relatively low operating costs and a low sludge generation rate. Sludge disposal costs are a factor in the cost of a biotreatment system. Biotreatment units can often be cost effectively retrofitted to existing O/W separators.

g. **Advantages**

Biotreatment has the potential for high overall efficiency. Operation costs of well maintained units are low. The capital cost of biotreatment units is comparable to that of gravity separators. Biotreatment systems are available as skid-mounted units making them suitable for transporting to various locations. Biotreatment units can be retrofitted to existing O/W separators. In some cases, it is possible to capture the off-gas from biotreatment reactors and use this energy to support the reactor, thereby lowering operating costs. AF bases that have FOTWs that can handle the sludge generated by biotreatment would be able to derive the most benefit from the process without the drawback of high disposal costs.

h. Disadvantages

The biologically active media has to be supplied with a continuous nutrient source. Replacement and/or replenishment of the treatment bed, and disposal of the generated sludge are important cost factors. Biotreatment may produce an off-gas that has to be further treated before discharge and the liquid effluent from biotreatment facilities tends to have a greater BOD. Biotreatment of oily wastewater is not a mature technology, and its performance in new applications cannot be predetermined. In most cases, detailed feasibility studies will be required.

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APPENDIX D

WORKING PRINCIPLES OF THE SELECTED TECHNOLOGIES

This appendix describes the working principles of the 10 selected technologies discussed in this report. These technologies, discussed in the subsections that follow are:

1. Gavitational Separation
2. Coalescers
3. Chemical Demulsification
4. Air Flotation
5. Centrifugal Separation
6. Air-sparged Hydrocyclones
7. Depth Filtration
8. Membrane Filtration
9. Electrical Field Separators
10. Biotreatment

A. GRAVITATIONAL SEPARATION

Gravitational separation is the most widely used O/W separation method. This technology uses the force of gravity to separate oil, water, and solids into different phases. Density differences drive the separation. In O/W separators, oil is separated from the denser water phase and is removed from the top of the separator while the water is removed from the bottom. Many gravity separators also have a grit chamber which allows solids denser than water to settle out. The separation of a mixture of immiscible fluids into separate phases can be modeled by Stokes Law for fluids (see Appendix A, Equation A-1).

Gravity-based O/W separators are found in a wide variety of configurations. Older separators are generally constructed of concrete, but current generation separators are often made of steel. When properly designed and used with an appropriate wastestream, gravitational separators are an inexpensive and low-

maintenance method of processing large volumes of non-emulsified oil-contaminated wastewater.

Individual wastestreams need to be analyzed to decide if a gravity separator is an appropriate technology as a gravitational separator is not applicable to all oily wastestreams. If the densities of the dispersed phases are similar or if the dispersed phase droplets are very small, the settling velocity will be too low and the separation will be severely limited. Detergents and other surfactants tend to emulsify oils, keeping them in very small droplets and preventing coalescence, thereby limiting the efficiency of gravity separators for oil water mixtures which contain detergents. Chemically stabilized emulsions generally require pretreatment before they can be separated in a gravity separator.

Simple decanting gravity separators and enhanced gravity separators are the two main types of gravity separators. Enhanced gravity separators usually incorporate coalescing devices to accelerate separation. Coalescing devices are described separately in the next section. The principles of simple decanting separators are described next.

Simple decanters are essentially large settling tanks that provide the O/W mixture time to naturally settle into discrete phases. Figure D-1 is the schematic for a simple decanting separator. Wastewater enters at one end and water, reduced in free oil content, flows out of the tank from outlets near the bottom or from under a partition or baffle. The lighter oily-phase collects on top of the water and is periodically removed from the surface. Separated oil can flow out of a wier as gravity brings it to the surface or it may be collected by a sweep arm, or some other skimming device. Heavy solids, and oil entrained in those solids, sink to the bottom of the separator and form a layer of sludge which is periodically removed from the tank to be disposed of as solid waste.

Separation of oil and water occurs in a simple decanter based on the principles of gravity separation described earlier. The most important design parameter for a gravity O/W separator is the residence time of the process stream (see Appendix A). Longer residence times lead to more effective separation but also require larger separating tanks. The larger the droplets of the dispersed phase, and the greater the

difference in the densities of the two phases, the more efficient the separation will be. Conditions of low turbulence are necessary for gravity separation to be effective.

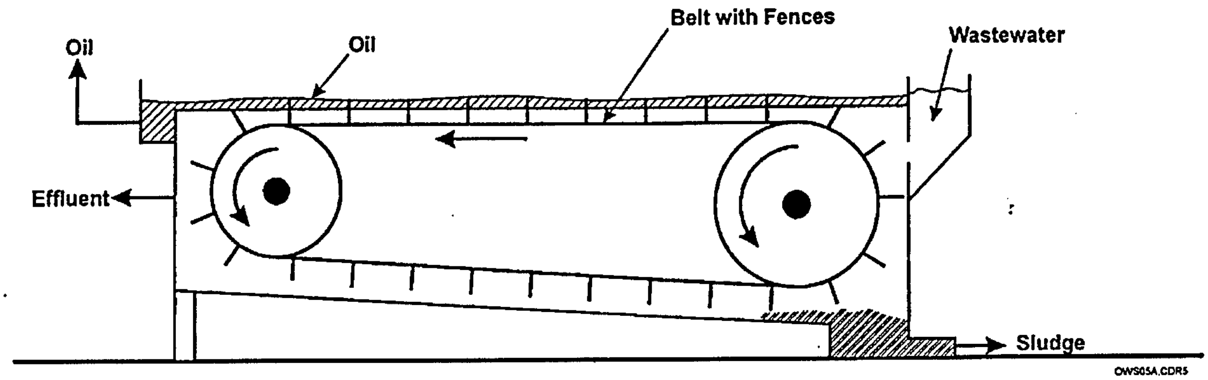


Figure D-1. Cross Section of a Simple Decanting Oil/Water Separator.

The most commonly used design standards for gravity separators are those set by the American Petroleum Institute (API). The following criteria have been developed by the API in the design of gravity separators.

- Minimum operating temperature of 40°F
- Maximum value of the specific gravity for the suspended oil is 0.85
- Minimum oil droplet size of about 150 μm

Separators designed according to API specifications frequently are referred to as "API separators" (see Figure D-1). API separators should be able to separate droplets larger than 150 μm completely but will not effectively separate smaller droplets.

Gravity separators are used throughout the petroleum production and refining industry to treat wastewater containing high concentrations of oil. Gravity separators are also used in a wide range of industrial processes including treatment of oily wastewater from cleaning operations.

Gravity separators are designed for a specific flowrate and specific minimum droplet diameter. They are designed to minimize the settling distance and the continuous phase velocity, and thus typically have large surface area to volume ratios. When operated within the design specifications, gravity separators can remove

significant amounts of oil and grease. However, increasing the flowrate to the separator decreases the oil removal efficiency by decreasing the residence time and potentially introducing turbulence. Small droplets can result from agitation and/or the addition of chemical stabilizers. Gravity separators are not effective on chemically stabilized emulsions. Cleaning operations, such as those at the AF bases, may involve high shear rinsing and addition of detergents and other cleaning products. Both actions favor the formation of kinetically stable emulsions that may not be gravity-separated.

B. COALESCERS

Coalescers are devices, often added to simple gravity separators, that enhance the performance of O/W separation. Coalescence is the physical joining together of very small droplets to form larger drops which then naturally separate into a single phase layer (see Appendix A). The actual role of the coalescer is to bring together small droplets of oil to create larger droplets of oil that can be separated more easily. Coalescers are COTS technologies and are available in many different forms.

Coalescence occurs when dispersed hydrophobic oils attempt to reduce the free energy associated with surface tension by forming larger droplets of greater volume but less total surface area. Oil droplets in water will attach preferentially to surfaces, particularly hydrophobic surfaces, and the oil phase will then wet the surface of the coalescing media to form a film. Additional oil droplets will coalesce into the film until the oil droplets are large enough to break away from the film and rise to the phase layer interface. Coalescing plates provide surfaces for the formation of this trickling film of oil that leads to a stratified, two-phase O/W separation (see Figure D-2).[D-1] Although all emulsions are unstable, many are sufficiently stable to separate efficiently in a gravity separation tank. With a coalescing device, small droplets that by themselves would not separate by gravity in a reasonable time coalesce into larger droplets which separate more efficiently.

Typical coalescing devices are plates, beads, meshes, screens, and membranes made from oleophilic materials such as polypropylene, nylon, polytetrafluorocarbon, glass, and glass treated materials. Coalescing beads and rotating fiber brushes of polypropylene also provide surfaces for coalescence. Coalescing fiber matrices offer

the highest specific surfaces for coalescing but lead to higher pressure drops across the device and greater fouling problems.

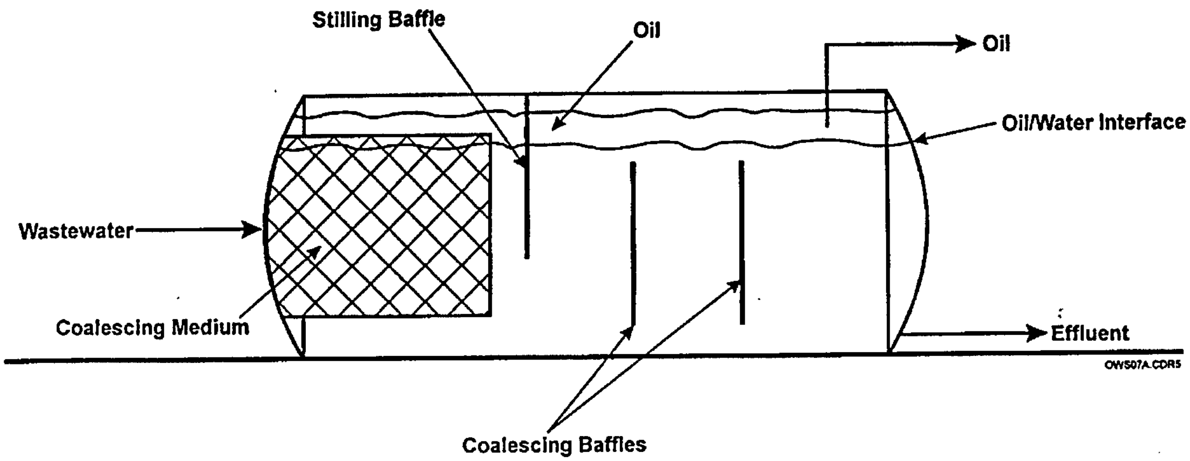


Figure D-2. Cross Section of a Coalescing Gravity Decanter.

An ideal coalescing device would consist of a composite device with stages of increasing particle size surface area and with a final stage that encourages the release of oil droplets from the solid material.[D-2] Coalescers can separate oil droplets that are 10 μm or smaller in diameter.[D-2] Droplets as small as 1 μm may also be removed by a coalescing device.[D-3] Coalesced droplets typically leave the coalescing device in droplet sizes ranging from 150 to 1,000 μm.

Coalescing devices are ineffective in removing chemically stabilized emulsions. A chemically stabilized emulsion has a decreased interfacial tension, and is less likely to coalesce. Fine suspended solids may also limit the effectiveness of a coalescing device because the solids often adhere to the surface of the coalescer and eventually clog it. The use of a prefilter usually keeps solids from fouling the coalescing device.

The velocity of the fluid flowing through the coalescing device is a key operating parameter. The velocity must be low enough that the droplets can grow sufficiently before being swept off the coalescer fibers. Commercial designs typically operate in the range of 1 to 10 ft/min.[D-3] Separators with coalescing devices usually require a

greater degree of maintenance and monitoring during operation than simple gravity separation systems.

While coalescers require some maintenance to ensure efficient operation, they reduce the size of the gravity separation unit. A gravity separation vessel acting with a coalescer unit can be as much as one third the size of the gravity separator alone.

Parallel-plates are an example of coalescing devices incorporated in simple decanting separators to enhance gravity separation. Parallel-plate separators have the same basic design as simply gravity separators with added packs of parallel plate coalescers (see Figure D-3). After entering a large tank, the influent passes through the parallel plates where the oil and water phases begin to separate; separation is completed once the flow leaves the plates. The plates often are corrugated to increase SAs and to enhance separation. They can be mounted horizontally or at an incline. Parallel-plate separators are widely used to treat refinery wastewater and separate bilge oil.[D-4]

The use of parallel-plates has the advantage of increasing separator efficiency without adding any moving parts or increasing the size of the separator. Parallel-plate units are often selected where space is a constraint. The spaces between the plates act as individual simple decanting separators reducing the distance the oil droplets must travel to reach a surface thereby reducing the residence time required to perform a given separation. When the oil droplets in each channel rise to the roof of the plate, the plate provides a surface for the coalescence of the oil droplets. Channeling the flow between the plates decreases turbulence in the system, leading to better separation.

Parallel-plate separators when compared to simple decanters, require a greater level of maintenance including cleaning of the plates. Despite improved oil-removal efficiency, parallel-plate separators still remain ineffective in separating chemically stabilized O/W emulsions.

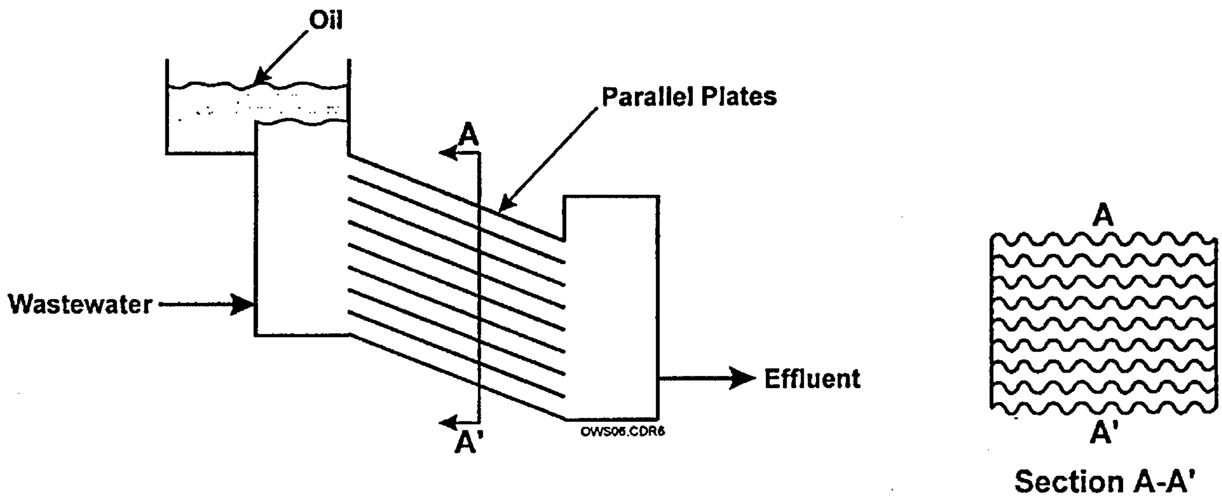


Figure D-3. Cross Section of a Parallel Plate Separator.

C. CHEMICAL DEMULSIFICATION

A chemically stabilized emulsion is caused by the presence of a surface-active agent, such as a surfactant, detergent, or soap. Anionic surfactants render the surface of the oil droplet negative in charge. Wastewater containing an emulsified oil is usually difficult and inefficient to treat using only physical separation processes alone. Emulsion removal by physical separation processes can be augmented by addition of chemical agents to break or destabilize the emulsion. Once the emulsion is broken, coagulants and flocculants can be used to hasten agglomeration of the oil particles formed. Chemical demulsification is applied to break stable O/W emulsions in a wide variety of wastewater and metal-finishing wastes.[D-5]

The effectiveness of a chemical to destabilize an emulsion depends on the emulsifier and emulsified oil. Anionic emulsions often can be destabilized by pH depression using an acid. Subsequent neutralization of the acidic solution results in a chemical floc, which absorbs oil droplets to separate the oil-solid material from the wastestream. Cationic metal salts (e.g., alum or ferric iron) and organic polyelectrolytes can also destabilize emulsions and aid in flocculation.

Addition of chemicals to break emulsified oils or suspended-solid contamination in water has several advantages:

- The chemical treatment system has a low cost for equipment and construction
- The treatment system is typically relatively simple and versatile
- When combined with other processes, chemical addition increases the overall separation efficiency, especially for emulsified oil

The major limitation of chemical addition for treating oil or suspended-solid contamination in water is that it produces a large amount of sludge, which requires further handling and disposal. Furthermore, a treatability study usually is required for identifying the chemical to be used, which often depends on the chemical composition (including the emulsifier, emulsified oil, and other organic and inorganic constituents) of the water to be treated.

D. AIR FLOTATION

Air flotation is a process used to separate suspended solids and/or emulsified liquids from wastewater by introducing fine air bubbles into the O/W mixture. The bubbles attach to the contaminants, or vice-versa, reducing the contaminant density to less than that of water. The resultant buoyant force of the combined air/oil/solid particle is sufficient to float the contaminants to the surface of the liquid for removal. Figure D-4 is a schematic of an air flotation unit. Oil is hydrophobic in nature and is attracted to the air/water interface, where it attaches as a droplet or film on the bubble surfaces. The oil/air mixture forms a froth phase on the surface of the water, and is then collected and removed. Three basic flotation methods are based on the mechanism of bubble formation:

1. ***Induced air flotation,*** which involves the use of agitators or gas spargers to form gas bubbles and often requires chemical addition. The bubble size often is large and not very efficient in collecting small liquid drops.
2. ***Electroflotation,*** which uses a direct current between a cathode and anode in the liquid to generate small oxygen and hydrogen bubbles in water solutions

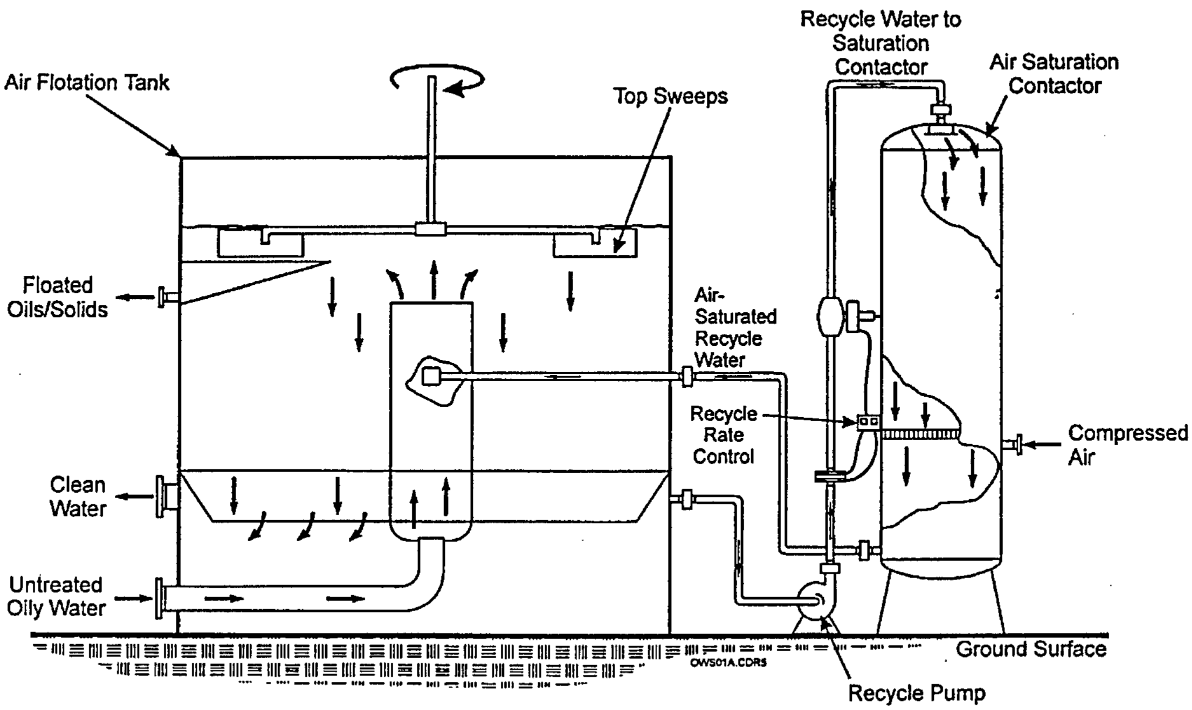


Figure D-4. Dissolved Air Flotation System.

1. ***Dissolved air flotation,*** the most widely used technique (Figure D-4). Air is dissolved in water in a compression tank and the mixture is fed into the flotation tank. The sudden decrease in pressure results in the release of very small air bubbles that attach to and cause flotation of the oil droplets and particulate matter.

Air flotation devices are commonly used in the oil refining industry, and perform as secondary separators by cleaning the effluent from API separators. Air flotation usually is applied near the end of an O/W separation train to remove contaminants at low concentration. The flotation option is particularly useful where the contaminant droplets or particulates have such low rates of separation that more conventional methods, such as gravity separation, are ineffective since low separation velocities may be caused by small droplet size and/or a particle density near that of water.[D-6,D-7]

Advantages of using air flotation for treating oil or suspended-solid contamination in water include:

- Air flotation is a mature COTS technology available from many vendors in a wide range of throughput capacities and construction materials
- Air flotation is an effective way of treating oily water, particularly if coagulation agents are added to increase the affinity of the contaminants to the air/water interface[D-8]
- With air flotation, less oily sludge is produced as compared to conventional bulk chemical reagent addition
- Electroflotation offers an effective, convenient, and controllable method of removing finely dispersed oil from aqueous emulsions where the performance can be adjusted by varying the electrical current. The effectiveness of electroflotation is not reduced by the presence of a surfactant.

However, there are limitations to using air flotation for treating oil or suspended-solid contamination in water:

- Application is limited to low concentrations of contaminants
- An off-gas stream is produced
- To work effectively, air flotation requires a density difference between the suspended particles and the water
- Induced and dissolved air flotation require bubble-generators, such as pumps, pressurized tanks, nozzles and pipes
- Electroflotation has a high operating cost due to electrical power requirements and is confined to the treatment of emulsions with a high salt content

E. CENTRIFUGAL SEPARATION

The centrifugal separators described in this section use rotation, induced by mechanical or hydrodynamic forces, to increase the separation velocity of oil droplets.

1. Mechanical Centrifuges

Mechanical centrifuges are used for separating materials of different densities. Centrifuges use inertial effects to generate the driving force for separating a mixture of two or more phases. Like simple sedimentation basins, centrifugal separators operate on the principle that acceleration will cause heavy particles to fall to the bottom and lighter liquids to flow to the surface. Separation is accelerated by centrifugal forces typically many times greater than the gravitational force that drives the separation in gravity separators. In centrifugal separation, the heavier phase is radially driven outward while the lighter phase is collected in the center around the axis of rotation (see Figure D-5).

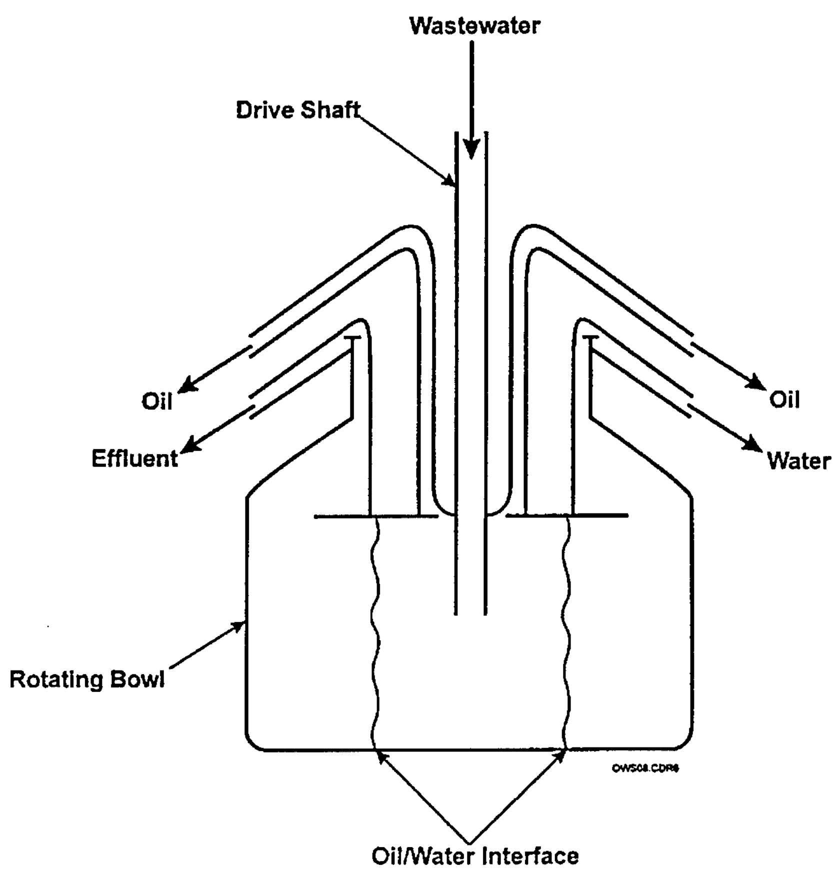


Figure D-5. Cross Section of a Bowl Centrifuge.

Sedimentation centrifuges operate to process a liquid stream either in batch or in continuous operation. Batch processes almost always allow the liquid a longer residence time than a continuous process. The longer the residence time, the greater the cumulative centrifugal force exerted on the liquids. Since sedimentation centrifuges also use the variable density of the liquids to affect separation, the longer the residence time, the greater the separation. Therefore, batch centrifugation can achieve greater centrifugal forces than continuous centrifugation, but is limited to considerably smaller volumes such as laboratory- or small-scale operations.[D-4] Continuous centrifugation can separate phases much faster than batch centrifuges for similarly sized equipment. For AF applications where the O/W waste stream flowrates are high, continuous centrifuges are a better treatment choice.

The performance of a centrifuge is determined by the rate at which particles of the dispersed phase separate from the continuous phase. In O/W separation, the dispersed phase consists of free and emulsified oil droplets and fine particles, and the continuous phase is water. The rate of separation, referred to as the settling velocity, is governed by Stokes Law (Appendix A, Section D), where the gravitational acceleration term is replaced by the centrifugal acceleration, $\omega^2 r$, where r = radius and ω = angular velocity. The rate of separation is increased as the density differential between the dispersed and continuous phases increases, the particle diameter increases, the centrifugal acceleration increases and/or the viscosity of the continuous phase decreases.[D-9]

Similar basic components are required for all types of continuous mechanical centrifuges. The influent stream is fed through a stationary feed pipe into a rotating cylindrical chamber powered by a motor. The lighter liquid phases migrate to the center of the cylinder where they are drawn out through an effluent pipe. The heavier liquid phases migrate to the outer sections of the cylinder and are drawn through a separate effluent pipe. Any heavy solids that are collected on the walls of the cylinder will degrade separation efficiency and damage the centrifuge if they are not removed during operation or periodic maintenance. Centrifugal systems are not very effective in separating stable emulsions and often require emulsion breaking steps

before centrifugation. The use of heating, pH adjustment, and/or chemical addition destabilizes an oil/water/solids emulsion that cannot be broken by centrifugal force alone. Destabilization is achieved by one or more of the following methods and is routinely applied in O/W centrifugal separation:

- Heat influent at 180° to 200°F to reduce viscosity, alter densities of oil and water, and potentially alter surfactant activity
- Adjust pH to alter surface charges and oxidize solid particles
- Add 150 to 3,000 mg/L of demulsifiers

After demulsification, the waste can be separated into oil and water components using a three-phase centrifuge.(D-10)

a. Bowl Centrifuges

One of the most common types of sedimentation centrifuge is the solid-bowl centrifuge. The solid bowl consists of a hollow cylindrical rotating element closed at both ends. A motor rotates the cylinder, and light liquids discharge through an overflow annulus near the axis of rotation. In three-phase separation (light liquid, heavy liquid, and solid), the heavier liquids discharge through an outlet farther from the axis of rotation. Solids collected on the wall of the cylinder are removed manually or automatically. Manual removal is accomplished by partially disassembling the centrifuge and cleaning the walls of the bowl.(D-4)

A solid-bowl centrifuge is often used as part of a treatment train for cleaning oily wastewater. Stable emulsions must be broken by a pretreatment step before separating the oil from the water.(D-10)

b. Disk Centrifuges

The disk centrifuge is another popular type of sedimentation centrifuge. As with the solid-bowl centrifuge the influent is introduced into a rotating chamber. The chamber of the disk centrifuge contains a stack of disks that stratify the flow of liquids, thereby improving the efficiency of separation. The disks actually are truncated cones spaced 0.3 to 3 mm apart and sloped at an angle of 35° to 45° from the axis of rotation. Light phases flow through the channels between disks towards the

axis of rotation, and heavier phases flow toward the walls of the centrifuge.[D-9] Disk centrifuges can operate at flows in the range of 20 to 400 gpm and can generate centrifugal forces up to 9,000 g.

Disk centrifuges of varying designs are used in a wide range of applications. Solid-wall disk centrifuges separate two liquids and retain any residual solids within the cylinder until maintenance; such centrifuges are used primarily for separating cream from milk. Valve-discharge centrifuges periodically discharge accumulated solids. Split-bowl centrifuges have a bowl that allows periodic "desludging" of the accumulated solids. Solids are desludged no more than once per minute and cannot contain any abrasive materials. Split-bowl centrifuges are used in the depulping of beverages. Peripheral nozzle discharge centrifuges continuously discharge solids.[D-4]

Disk centrifuges are ideal for separating two immiscible liquids, provided that the density differential is large; an emulsion of inadequate differential density cannot be separated. Whereas solid-bowl centrifuges can process high-solids-content flows, disk centrifuges are limited to processing streams with less than 10% solids, and experience some decrease in efficiency unless operated at far less than 10% solids. Viscous or gummy liquids can decrease performance by blocking channels between disks and plugging outlets.

Mechanical centrifuges are a mature COTS technology available in a wide range of sizes and construction materials. Their key advantages are:

- They rapidly separate two materials of different density. A light oil phase and a heavy sludge phase can be separated from water in a single-unit operation. A solid-bowl centrifuge quickly processes feed that a gravitational separator would process much more slowly or, in the case of very fine solids and very small droplets of dispersed liquids, would not be able to separate at all.
- Routine operation within unit design specifications is relatively simple

There are, however, some limitations to mechanical centrifuges:

- The effectiveness of centrifugation is limited by feed parameters. Materials with an insufficient density differential are not separated efficiently. For example, emulsified oil droplets may have a density that is too similar to the density of the continuous water phase and may not be separated.
- External power is required to run the rotor and power and necessary pumps
- Centrifuges are often noisy, requiring worker protection or noise abatement devices

2. Hydrocyclones

Like centrifuges, hydrocyclones use centrifugal inertia to separate oils and suspended solids in wastewater. However, the hydrocyclone does not consist of a rotating chamber. Centrifugal forces are created as follows. The wastewater enters the top of a conical tube and is introduced tangentially at the top of the hydrocyclone thereby, generating an angular velocity component (see Figure D-6). The angular velocity of the inlet stream generates the centrifugal force that causes the separation. The heavier phase, usually water and solids, is driven to the hydrocyclone wall and discharged as the underflow. The lighter phase migrates to the center of the hydrocyclone, reverses axial direction, and spirals upward, exiting the cyclone through an overflow pipe.[D-4]

Hydrocyclones are useful for separating solids from liquids or two immiscible liquids of differing densities. The hydrocyclone is a COTS technology that is employed in series with or in place of gravity O/W separators. Hydrocyclones are used to treat petroleum process waters, pulp and paper waste, metallurgical fluids, and drilling muds.[D-4]

The performance of a hydrocyclone generally is measured by its efficiency of removing oil from water given by:

$$Efficiency = \frac{Oil\ Removed}{Oil\ In\ Feed} = \frac{1 - C_{underflow}}{C_{influent}} \qquad \text{(D-1)}$$

where C is the mass flowrate. The efficiency of a hydrocyclone is frequently determined by optimizing the following set of operating parameters:(D-11)

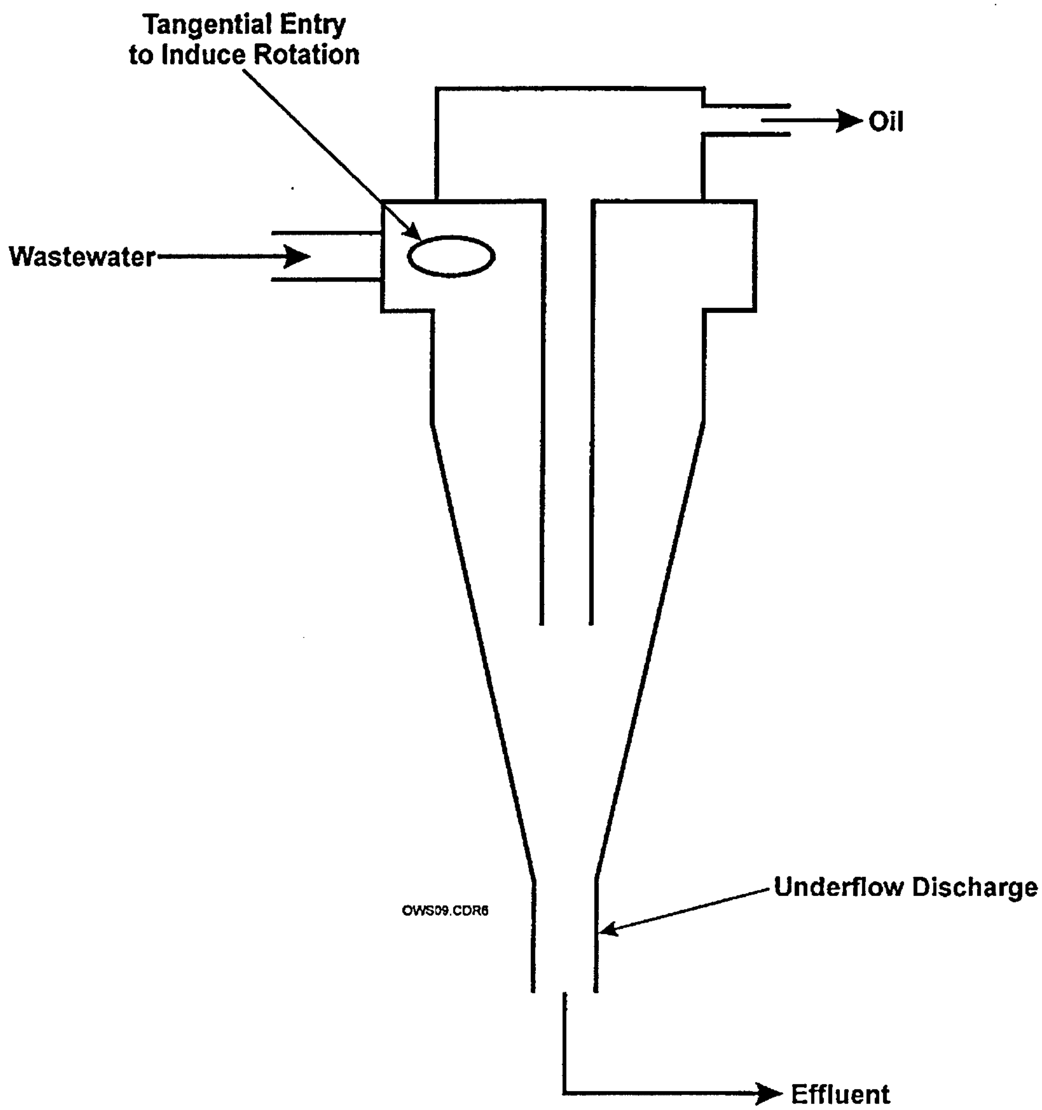


Figure D-6. Cross Section of a Hydrocyclone.

- ***Flowrate.*** At higher flows, the centrifugal separating force is larger but residence time in the hydrocyclone is decreased; at lower flow, forces are lower and residence time is higher. Hydrocyclone systems have operated for flows up to 3,000 gpm.

- ***Underflow Pressure.*** A backpressure is necessary at the underflow so that the lighter phase will be forced out the overflow. Pressures of 60 to 75 psi are typical.
- ***Overflow Diameter.*** Larger diameters often allow too much water to exit with the lighter oil phase, but larger diameters more adequately accommodate fluctuation in influent oil concentration.
- ***Oil Droplet Distribution.*** The size of the oil droplets has a very large impact on hydrocyclone performance. Larger droplets are more efficiently removed.
- ***Pressure Drop.*** The pressure drop across the hydrocyclone must be at least 30 psi to get adequate O/W separation. Performance improves as the pressure drop increases.
- ***Hydrocyclone Dimensions.*** A large variance in dimensions is allowable. Dimensions that are important to performance are cylinder diameter, cylinder length, cone angle, and underflow length. Larger dimensions allow longer residence times at higher flowrates.

Hydrocyclones offer several potential benefits over other O/W separation technologies. Hydrocyclones provide a centrifugal acceleration to increase the separation rate over that of gravitational separators. Hydrocyclones provide less effective gravitational force than mechanical centrifuges; however, hydrocyclones do not have complex and expensive moving parts such as high-speed rotating seals that can be high maintenance items. Hydrocyclone systems are easily transportable and are very compact, making them useful for remote operations. Because there are no moving parts, the operations and maintenance costs are minimal. Ideally, a hydrocyclone is fed by pressure from the process that it is treating, and no additional pumps are necessary.

The performance of hydrocyclone separation is limited by the droplet size and the density differential between the phases to be separated. Successful separations can be achieved on droplets as small as 10 μm in diameter. The difference

in the densities of the phases must be greater than 0.05 g/cm^3 for successful separation. The presence of emulsified oil decreases the density differential and may interfere with separation. Upstream devices should be limited to prevent the formation of smaller oil droplets. Hydrocyclones can handle wastestreams with as much as 30% light phase. The liquids must be immiscible and optimally will have a low viscosity. Hydrocyclones can handle some solids, but perform best when solid loadings are low.[D-12] The performance of the hydrocyclone has been demonstrated for several oil and water wastestreams.[D-13]

F. AIR-SPARGED HYDROCYCLONES

Air-sparged hydrocyclone (ASH) technology combines the centrifugal separation of a hydrocyclone with the froth-flotation principles used in dissolved air flotation.[D-14] The ASH has many features in common with a traditional hydrocyclone. It consists of a porous tube that is jacketed by a larger, nonporous tube. A conventional cyclone header is mounted on top of the porous tube, which has outlets at each end to allow water to exit. As in conventional hydrocyclone operation, the wastewater stream is fed into the cyclone header tangentially. The feed water develops an angular velocity component as it swirls down through the porous tube. This angular velocity provides the centrifugal force driving the separation of the heavy phases from the light phases. As the water flows through the porous tube, pressurized air is passed through the tube's shell to introduce a large number of tiny air bubbles into the water stream. Oil droplets and oily solid particles collide with the bubbles and are transported radially into the center of the hydrocyclone, then up to the core of the cyclone, and finally out through the overflow opening. Heavier phases, usually water, pass through the underflow.

The porous tube introduces the air through pores 35 to 140 μm in diameter with a typical porosity of 60%. The high-sped swirl flow on the inner surface wall of the porous tube enhances the generation of numerous fine air bubbles (diameters of about 100 μm). The hydrophobic nature of oil droplets leads them to concentrate at the air/water interface that is created by the presence of the bubbles.

The presence of stable emulsified oil droplets decreases the oil's hydrophobicity and impedes the transport of oil by attachment to the bubbles. In such cases, pretreatment of the wastestream for emulsion breakdown may become necessary.

The ASH performance is affected by the dimensions of the hydrocyclone and by the air flowrate, wastewater flowrate, oil concentration, droplet size, differential density, and reagent dosage. As with a conventional hydrocyclone, the separation efficiency improves as the droplet size and differential density increase. The air and water flowrates and the demulsification reagent dosage have to be optimized through feasibility studies.

The ASH technology is an emerging technology that has been demonstrated at the pilot-scale stage.[D-14,D-15] The technology is applicable to oil removal from water, heavy metal removal, VOC removal, and dense, non-aqueous-phase liquid (DNAPL) removal.[D-15]

G. DEPTH FILTRATION

Depth filtration is a method of separating emulsified oil and suspended solids from a liquid by forcing the contaminated fluid through a porous medium. As the liquid flows through the bed, oil droplets and solids are captured and retained inside the medium by various physical and chemical forces. Depth filtration of industrial wastewater is usually carried out in filter media that are absorbent fibers and/or granular materials like clays or activated charcoal.

1. Absorbent Fiber Media

Absorbent fiber media comprise a natural or synthetic fiber-based porous substrate impregnated with a hydrophobic agent. When oily wastewater passes through a closed container filled with fibrous material, oil droplets and suspended solids are entrapped and removed throughout the bed. The fibrous media acts like a coalescer to remove the oil.

Absorbent fiber media filtration (see Figure D-7) is a mature COTS technology in the field of controlling and cleaning up oil spills. Application of fiber-filled containers to remove oil emulsions from wastewater streams is a more recent development but still can be considered a COTS technology. Fiber media can be used

as a pretreatment to prevent surface fouling of activated carbon, ion-exchange resin, or membrane filters. It can also be used to polish the effluent from air-flotation, gravity, or centrifugal separation systems.

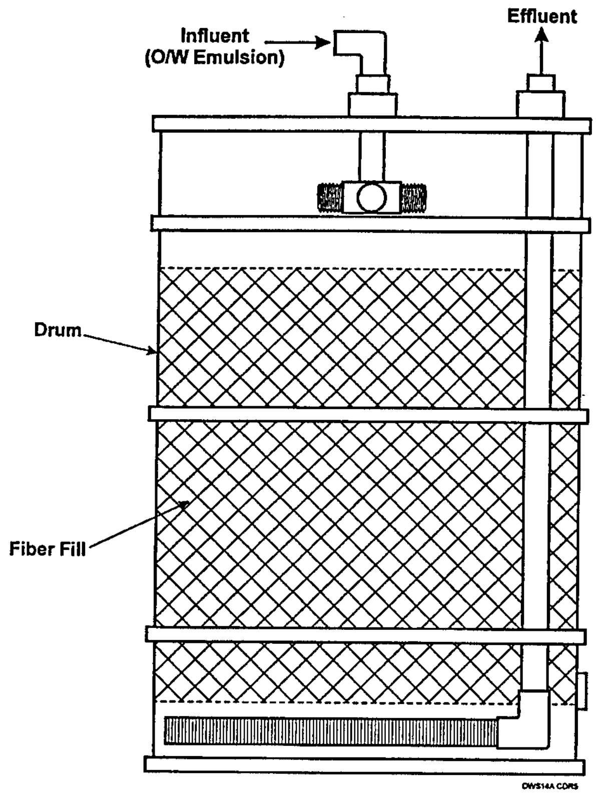


Figure D-7. Treatment System Canister Filled with Oil-Sorbent Fiber.

The key advantages of using absorbent fiber media for treating oil or suspended-solid contamination in water are as follows:

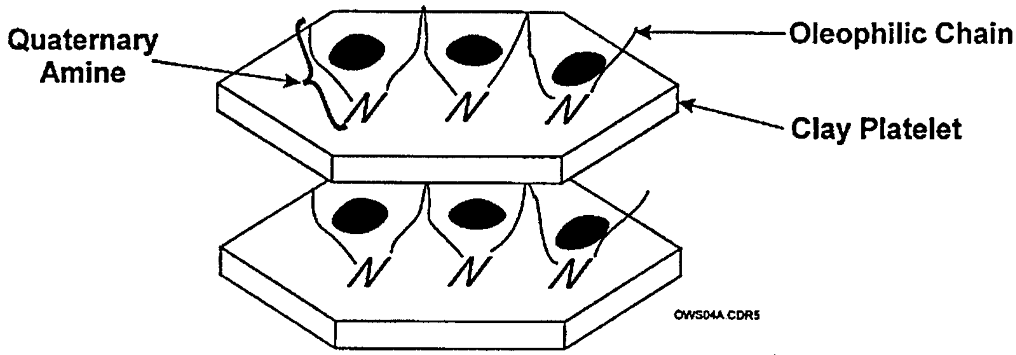
- The media are easy to use and are available in a wide variety of configurations and treatment capacities
- Absorbent fiber media can be used as pretreatment devices and eliminate fouled membrane filters and clay beds
- Some absorbent fiber material can coalesce and entrap emulsions and oils without the use of chemicals, heat, vacuum or special equipment

However, the main limitation to using absorbent fiber media for treating oil or suspended solid contamination in water is that some absorbent media cannot be regenerated or reused, and must be disposed of as hazardous materials.

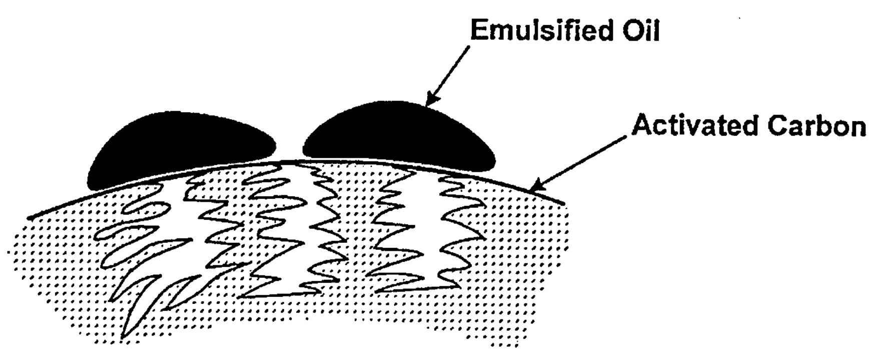
Many types of fibers, such as cotton, dynel, fiberglass, asbestos, peat, and even stainless steel, have been used for removal of oil from water. Fiberglass is a relatively cheap and cost effective fiber. It can trap suspended particles and oil droplets and provide a low oil content in the water discharge. Because it has densely woven and tightly packed fibers, oil concentrations less than 1 mg/L are achievable. One of the first recorded application of fiberglass to remove oil from water was conducted in a 5-inch bed of compressed 7-μm fibers.[(D-16)] Fiberglass coalescer beds may be regenerated by methanol.[(D-17)] Polypropylene can remove high concentrations of suspended solids, oil droplets, and detergents by the natural attraction of oil to polypropylene. Chemical pretreatment may be required for extreme concentrations of colloidal, detergent, or O/W emulsions. Simple steam-cleaning may restore the polypropylene for reuse. One commercially available medium, produced by BoniFibers H™, is a synthetic carbon/hydrogen fine fiber medium.[(D-18)] Kuwahara, et al., also have patented natural fiber oil-absorbing media.[(D-19)]

2. Organoclays

Organoclay is a quaternary amine-modified granular bentonite clay or zeolite. When the nitrogen end of a quaternary amine is exchanged onto the surface of the clay (see Figure D-8[a]), the clay becomes organophilic, absorbing organics and not water. If a long-chain quaternary amine such as dioctodecyl-dimethyl-ammonium bromide, hexadecyl-benzyl-dimethyl-ammonium chloride or dimethyl (di-hydrogenated) tallow ammonium chloride (12-18 carbon) is used, the clay will swell in organic fluids such as diesel and jet fuel, gasoline, kerosene, and other oils.[(D-20,D-21)] In the presence of water; the carbon chains from the quaternary amine, will stand up to a perpendicular position from the clay plate as shown in Figure D-8[a].[(D-22)] These chains then will dissolve into the oil or other hydrocarbon droplets, holding or fixing the droplets by means of Coulombic forces.



(a) Organoclay Removing Emulsified Oil.



(b) Pore Spaces of Activated Carbon Blinded by Emulsified Oil.

Figure D-8. Modified Clay Oil Sorbent. (Note: For illustrative purposes only. Not to be construed as a vendor endorsement.)

When activated carbon alone is used as the adsorbing media, emulsified oil droplets larger than the diameter of the pores in the activated carbon tend to block the pores preventing further adsorption (Figure D-8[b]). Problems with fouling of activated carbon can be reduced by using an organoclay/anthracite mix as a pretreatment step prior to treatment in an activated-carbon vessel, resulting in cost savings.

Filters for organoclay applications typically consist of a tank with an underdrain covered by a porous grid supporting a bed of granular modified clay with a typical depth of 3 to 6 feet. A feed distribution manifold feeds the wastewater uniformly to the top of the bed typically at 2 to 10 gpm/ft^2. The top of the tank is open if gravity is the driving force and closed for pressurized filtration.

Organoclay sorption of oil is a mature COTS technology available in a variety of throughput capacities and materials of construction. Organoclay can be used to remove mechanically emulsified oil, grease, and other sparingly soluble large chlorinated hydrocarbons from water. Applications for organoclay are varied and include cleanup of stormwater, steam condensate, produced water from oil production wells, API O/W separators, degreasing operations, truck and heavy equipment wash, and other manufacturing process water.

The main advantages of using organoclays for treating oil or suspended solid contamination in water are as follows:

- Organoclays can be used as a pretreatment for activated carbon, ion exchange resins, membranes and other media to reduce usage of more expensive components
- Organoclays can further treat the water after DAF units and other O/W separation, in a cost-effective manner, to bring the water into compliance with discharge limits
- Organoclay units are simple to use, and are available commercially to handle a wide range of flowrates

The limitations for using organoclay to treat oil or suspended solid contamination in water are:

- Organoclays are generally more expensive than the common filter media
- Used organoclay media cannot be regenerated for reuse and will require disposal

Figure D-8 [a and b] shows an example of a large-scale application, where three tanks containing organoclay media protect four granular activated carbon columns.[D-23] The influent is washwater from a jet plane cleaning process and

stormwater runoff containing oil, grease, heavy metals, and other organic compounds. Depending on the size of organoclay absorbers, the organoclay can last as long as 2 years before changeout becomes necessary.

H. MEMBRANE FILTRATION

Membrane filtration separates mixtures of materials based on differences in particle or molecule sizes. The driving force behind membrane filtration is the transmembrane pressure differential, which is the pressure drop from one side of the membrane to the other. Materials that are smaller than the pores of the membrane pass through the membrane and are known as the filtrate or permeate. Materials that are larger than the pores of the membrane do not pass through the membrane and are referred to as the retenate or the concentrate (see Figure D-9).

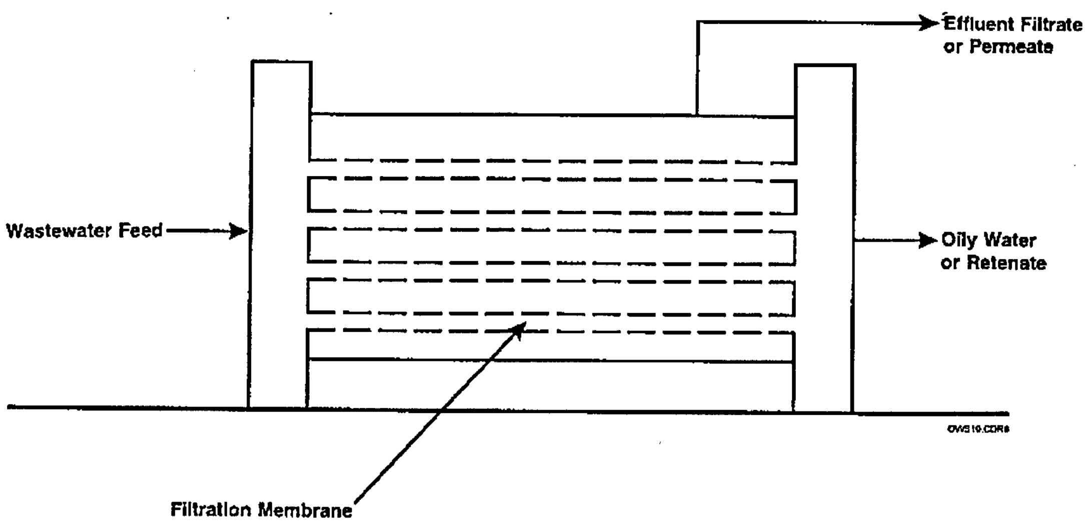


Figure D-9. Cross Section of a Membrane Filter.

Membrane filtration processes are classified according to the pore sizes. Microfiltration (MF) includes membranes with nominal pore sizes between 0.2 and 1 μm. Ultrafiltration (UF) membranes have nominal pore sizes in the range 0.01 to 0.2 μm. Reverse osmosis (RO) membranes have nominal pore sizes in the range 0.0001 to 0.001 μm, or are used to reject compounds with molecular weights below

300.[D-24] Further discussion will be limited to MF and UF separation technologies, as the AF facilities do not need to purify water to the high standards of RO.

The very nature of filtration processes leads to a wide variety of process streams that can be treated with MF or UF. These filtration methods are used in the purification of water for potable or laboratory use, in pharmaceutical processes, in chemical recovery processes, and for O/W separation, especially in metal-working and metal-finishing industries.[D-24]

MF and UF may be classified into crossflow and dead-end configurations. When retentate flows in a plane parallel to the surface of the membrane, the configuration is crossflow, as in spiral wound, hollow fiber, stirred cell, and tubular geometries. The most common design for membrane filters for ceramic membranes (see Figure D-9) are hollow fibers, flat plates, and spiral wound sheets for polymeric membranes.[D-25] If there is no flow, other than that perpendicular to the membrane surface, the systems is said to be in dead-end configuration.

Maintaining the flow rate of the permeate per unit area normal to the membrane (flux) is the biggest challenge in membrane filtration. "Flux decline" may be categorized into fouling phenomena and concentration polarization.[D-26] Fouling phenomena, such as solute adsorption, membrane pore blocking, and solidified solute deposition, are generally difficult or impossible to reverse. Concentration polarization occurs when the solute or particulate matter carried to the membrane by the solvent flux is unable to pass freely through the membrane and thus will accumulate near the membrane.[D-26] It is generally a reversible process. The concentration polarization layer can be removed by diffusion or by physical means. Crossflow filtration will minimize the effects of concentration polarization by sweeping the layer away by convection.

Membrane filtration systems may be modeled by assuming that the permeate flow is proportional to the transmembrane pressure differential and inversely proportional to the resistance leading to the pressure differential. Pressure resistances may include those due to the membrane, the polarization layer, the membrane adsorbed material, and a gel layer if present as is shown by the Darcy's Law-type expression:

$$J = \frac{\Delta P - \Delta \pi}{\eta_0 (R_m + R_a + R_{pl} + R_g)} \quad \text{(D-2)}$$

Where:

J = The solvent flux

ΔP = The transmembrane pressure drop

$\Delta \pi$ = The osmotic pressure difference between the feed and the permeate

η_0 = The permeate viscosity

R_m = The membrane resistance

R_a = The adsorbed solute resistance

R_{pl} = The polarization layer resistance

R_g = The gel layer resistance[D-27]

Membrane filtration systems can be designed to separate a wide variety of two-phase liquid mixtures and solid-in-liquid mixtures. There are, however, some general limitations and disadvantages to membrane filtration. Membrane filtration systems are frequently not capable of the flows that can be achieved by other processes such as gravitational or centrifugal separators. Fouled membranes require periodic cleaning or replacement. Fouling occurs in all membrane systems and is increased with increasing levels of solids. A successful system requires frequent monitoring of operating conditions, adding to operating expenses. These operating and maintenance requirements often make a membrane filtration system an expensive alternative.

Wastewater treatment membrane materials can be classified into polymeric and ceramic membranes.

1. Polymeric MF/UF

Polymeric membranes for MF and UF are available in a wide variety of materials such as cellulose acetates, polysulfonics, polyacrylics and polyamides.[D-25,D-28] Table D-1 lists some membrane types and their operating conditions. Polymeric membranes can be used in a variety of configurations, and can be manufactured for pore sizes throughout the UF and MF spectrum. Polymeric membrane filtration is a COTS technology. While it may be considered a mature

technology in many applications, it is an emerging technology in O/W separation applications mainly due to problems with membrane fouling.

TABLE D-1. EXAMPLES OF POLYMERIC MEMBRANES AND OPERATING RANGES.[D-25]

Membrane Material	Operating pH Range	Operating Temperature Range (°C)
Cellulose acetate	2.5 to 7	0 to 50
Polysulfonic	<1 to 13	0 to 79

Polymeric membranes are generally less expensive than ceramic membranes, but they are not resistant to extremes of pH and temperature. Polymeric membranes systems require regular operator attention and maintenance, requirements that would contribute to system costs. A membrane system would operate ideally as one that periodically processes a wastestream and not as a system that requires continuous year-round operation.

2. Ceramic MF/UF

Ceramic membranes are constructed with pore sizes ranging from 0.01 μm to 5 μm and can be used in many applications including O/W separation. UF membranes are made of zirconium oxide (ZrO_2) or γ-alumina (γ–Al_2O_3), and MF membranes are made of α-alumina (α- Al_2O_3). These membranes usually are constructed to be on the outside or top of intermediate and support layers of larger pore membranes made of α-alumina. Typically, ceramic membranes are configured for crossflow filtration. Membrane elements are packed in stainless steel housings that can contain multiple membrane elements. The housing acts as a shell to capture the permeate and to regulate the flow of permeate and the transmembrane pressure differential.[D-29]

Ceramic membranes have good physical integrity, high resistance to temperature differences, and the ability to process solutions over the entire range of pH values from 1 to 14. Ceramic membranes have been used for O/W separation and for

solid/liquid separations. Membrane performance can be prevented from downgrading by using techniques such as backpulsing and membrane cleaning.

Membrane performance can be measured by evaluating both the ability to remove oil and grease from a solution and the decrease in permeate flux with continued use. Many studies have evaluated the ability of ceramic membranes to remove oil and grease from wastestreams, and reductions in the permeate flux.

The ceramic membrane is an emerging technology. They are more expensive than polymeric membranes. As with polymeric membrane systems, ceramic membranes also would involve higher operation costs.

I. ELECTRICAL FIELD SEPARATORS

Electrical processes use a strong electrical field to break emulsions, which are stabilized by electrokinetic effects induced by surfactants. When the oil emulsion is passed between two electrodes, the negatively charged oil droplets are attracted to the positive electrode and coalesce in a position where they can be separated by gravity. Figure D-10 is a schematic of flow and electrical field arrangements in an electrical field separators.

1. Electroacoustic Separators

In electroacoustic separation, an electrical field and an acoustic field are applied simultaneously to separate fluids from suspended particles. Combining the two has synergistic effects. The electric field neutralizes charges on the particle, causing them to agglomerate; it also causes the particles to move away from the electrode (which is usually permeable) thus reducing clogging of the filter medium. The acoustic energy produces very high inertial and elastic forces at the solid/liquid interface, reducing the effective viscosity and surface tension of the fluid, and this in turn eases diffusion and migration of the liquid and improves overall dewatering.

Electroacoustic separation commonly is applied to dewatering slurries or suspensions such as coal slurries and sewage sludges.[D-30] It can enhance treatment efficiency when combined with other technologies such as filtration.[D-31]

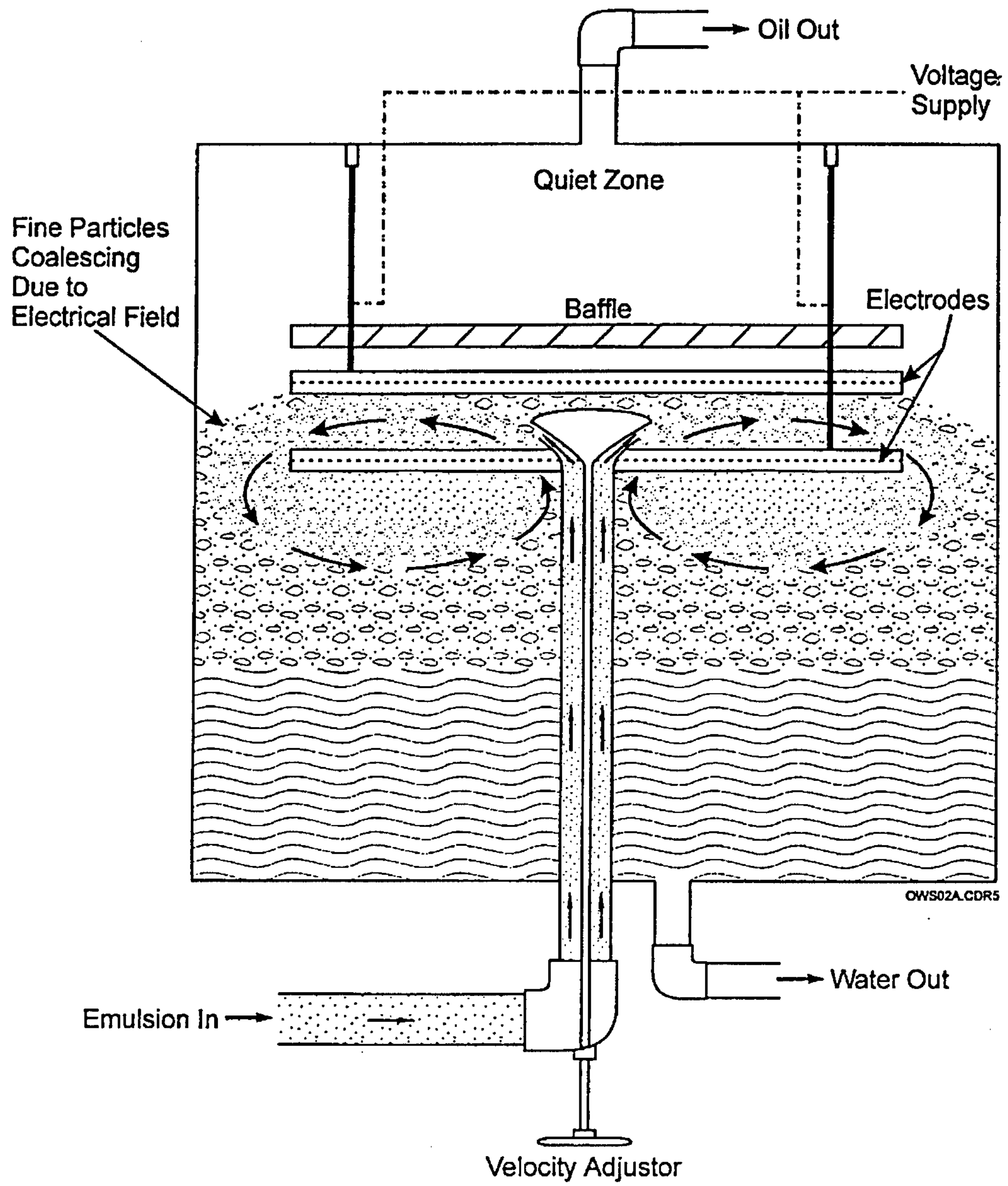


Figure D-10. Electrical Field Coalescing Separator.

The main advantage in using electroacoustic separation is that it is more effective than mechanical dewatering methods in achieving a high solids concentration or liquid removal when treating water contaminated with oil and suspended solids.

However, the use of this technology is currently limited by the operating cost due to the high electrical energy consumption and that it is not a well established for treating O/W emulsions.

2. Nested Fiber Filter

Nested fiber filter demulsification is a novel technology tested by Battelle at a bench-scale level for the treatment of oily water, including both mechanically and chemically emulsified oil.[D-32] The treatment system consists of a container with a stainless steel nested fiber bed to which an electrical field can be applied. The oily wastewater is directed upward by two baffles at the entrance to the container so that larger oil drops can be separated before they reach the packed steel fiber bed (the bed depth is 15 inches). An experimental study conducted at Battelle reported that the stainless steel nested fiber filter alone, without the application of an electrical field, had a removal efficiency of 80% for mechanically emulsified oil. The removal efficiency increased to 90% with the application of an electrical field. If a surfactant (i.e., chemically emulsified oil) was present, the average removal efficiency was 80% with an electric field. The nested fiber filter technology is not commercially available.

J. BIOTREATMENT

Biological treatment involves biological degradation using living microorganisms to digest the organic compounds in the wastestream. Biotreatment of municipal and industrial wastes, such as oily sludges and wastewater, has become a common form of treatment in recent years. Biotreatment is also very popular in the petroleum and manufactured gas industry. However, biotreatment of oily wastewaters of the type encountered at AF facilities has been limited. Most biotreatment facilities are operated for the removal of listed toxic organic wastes such as BTEX. Oil and grease removal, if any, usually is an added benefit.

Biodegradation processes are classified as either aerobic or anaerobic. Aerobic processes require the presence of oxygen to proceed, while anaerobic processes occur without oxygen. The by-products from each of these processes are quite different. Aerobic processes generate carbon dioxide, water and organic residue, whereas anaerobic processes generate methane and carbon dioxide. Anaerobic processes are not suited for O/W removal.[D-33]

The overall advantages of biotreatment processes are as follows:

- The biomass is capable of regenerating on its own

- Treatment methods do not require harsh chemicals or dangerous machinery, thus reducing threats to worker safety
- Industrial boitreatments are designed for automatic operation, which reduces operating costs
- In anaerobic processes the off-gas stream generated can be used as a fuel source, and sometimes significantly offsets energy requirements of the system
- The generated sludge is generally a biologically stable end product with good dewatering capabilities

Disadvantages associated with biotreatment are as follows:

- Biotreatment is generally capable of treating wastewater that contain only dilute amounts of contaminants
- Biotreatment is sensitive to pH and temperature. The optimum pH for aerobic processes is 6 to 8, and for most systems the pH must be maintained between 5 and 9. Typical biotreatment systems operate in the range of 10° to 30°C. However, at higher temperatures the metabolic rates and removal efficiencies are enhanced, and in some cases may prove to be cost effective to increase the operating temperature.
- In addition to being applied under a narrowly defined set of operating conditions, biotreatment processes can generate a considerable amount of sludge and can produce bad odors
- Discharge from biotreatment facilities have the tendency to have a greater biological oxygen demand (BOD)

Biotreatment may be considered an emerging technology when aimed at specifically removing oil and grease from wastewaters typical to those generated at the AF bases. However, as they are capable of degrading a variety of hydrocarbons including oil and grease, they have the potential to be applied as small scale units to individual facilities. The discharge from these facilities will potentially have reduced

needs for further treatment, which in turn can significantly lower the load on an IWTP or POTW that is downstream.

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APPENDIX E
TEST PLAN

The field test program was conducted between May 27 and July 17, 1997, in two parts. Part 1 was conducted between May 27 and June 19, 1997, and Part 2 between July 7 and July 17, 1997. The test program set-up, test parameters, sampling procedures, and analysis procedures are discussed in the following subsections.

A. TEST SET-UP

The primary evaluation site for the test program was the O/W separator servicing the ACWRs located in Building 583. This separator processed the largest amount of oily wastewater at Dover AFB, and was the most suitable site for conducting dynamic real-time testing during aircraft wash cycles.

The VWR and the JETC were not suitable sites for dynamic testing because of the low volumes of washwater generated, the intermittent nature of the washing schedules, and lack of reasonable access to representative streams from the respective processes. The lagoon system is unique to Dover AFB. It is not representative of typical AFB O/W separators. Sample streams drawn from the lagoon would not be indicative of a single process but a number of activities at the base. Therefore, it was decided that the primary test site would be at Building 583.

All of the primary and secondary treatment technologies were dynamically tested at the O/W separator in Building 583. Samples of washwater discharges from the VWR, JETC, and the lagoon were transported for testing on the membrane unit installed at Building 583. The biotreatment test system was set up at the lagoon. (Figure IV-6 in Section IV is a photograph of the biotreatment system at the lagoon.)

At the test site in Building 583, all of the technologies were tested simultaneously using a manifold system. A sample slipstream was drawn directly from the ACWR washwater discharge pipe and distributed to the various separators using the manifold system. The manifold system consisted of a 2-inch sampling line manifolded to six 1/2-inch lines. Flow through each 1/2-inch line could be regulated by two flowmeters, a high-flow rotameter and a low-flow rotameter, that gave a flowrate control span ranging

from 0.1 to 5 gpm. Wastewater samples were drawn from the discharge pipe using an air diaphragm pump. The manifold system was designed and fabricated at the ARCADIS Geraghty & Miller workshop in Mountain View, California. Figure E-1 is a group of photographs showing the test setup, including the manifold system and its various components, in Building 583. Figure E-2 is a schematic of the manifold system. The figure shows the set-up used in the Part 2 testing. For the Part 1 testing, the baseline SGS unit was also connected to the manifold as a primary treatment process, the chemical treatment system was not tested, and the ClaySorb unit served as a secondary treatment process treating PC discharge for some Part 1 tests, and was connected to the manifold as a primary treatment process for other Part 1 tests.

A biotreatment system was also set up at the lagoon, incorporated into a second SRC-M2 unit. The bacteria and the nutrients were maintained in aqueous solutions in plastic 5-gallon containers and were delivered, using peristaltic pumps, into the SRC-M2 unit once every 24 hours. The wastewater stream for treatment was drawn from the lagoon and sent to the test unit via a submersible centrifugal pump.

B. TEST PARAMETERS

Two key parameters were varied over the course of the test program:

1. <u>Treatment residence time</u>. The residence time of the wastewater in each of the primary treatment devices was varied by changing the influent flowrate. The residence time was varied to simulate the actual residence time ranges for the wastewater in the O/W separator in Building 583, thereby allowing the evaluation of separation effectiveness as a function of treatment residence time. Table E-1 summarizes the operating range of the residence time and the respective flowrate settings for the primary treatment separators tested in this program.

2. <u>Oil and grease concentration</u>. Various levels of influent O&G concentrations were encountered in the different washwater streams. In addition to the actual levels of O&G in the washwater streams, a set of tests was conducted by spiking the primary treatment systems with high oil concentration slugs. Table E-2 summarizes the O&G concentration range tested.

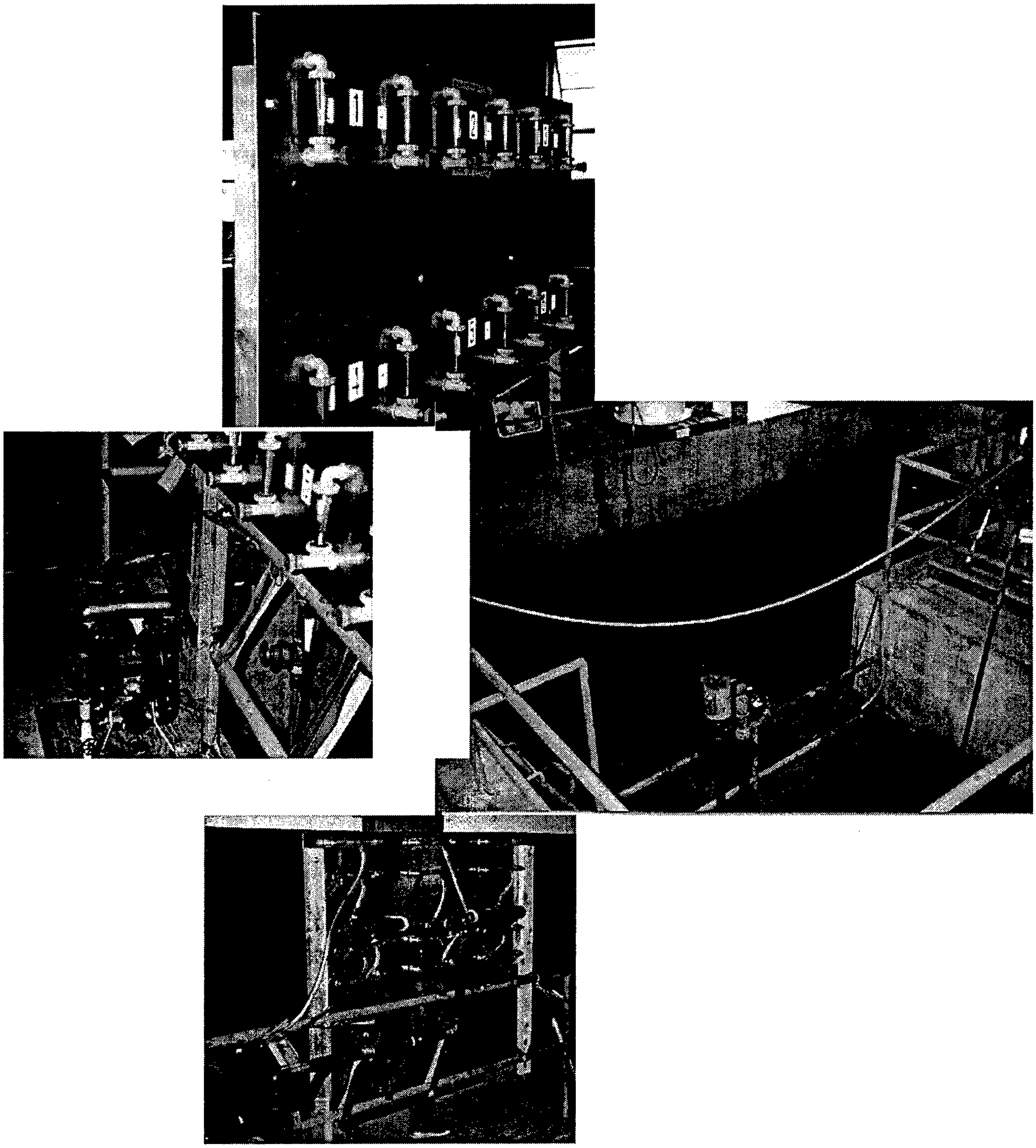

Figure E-1. Photographs of the Test Set-up in Building 583.

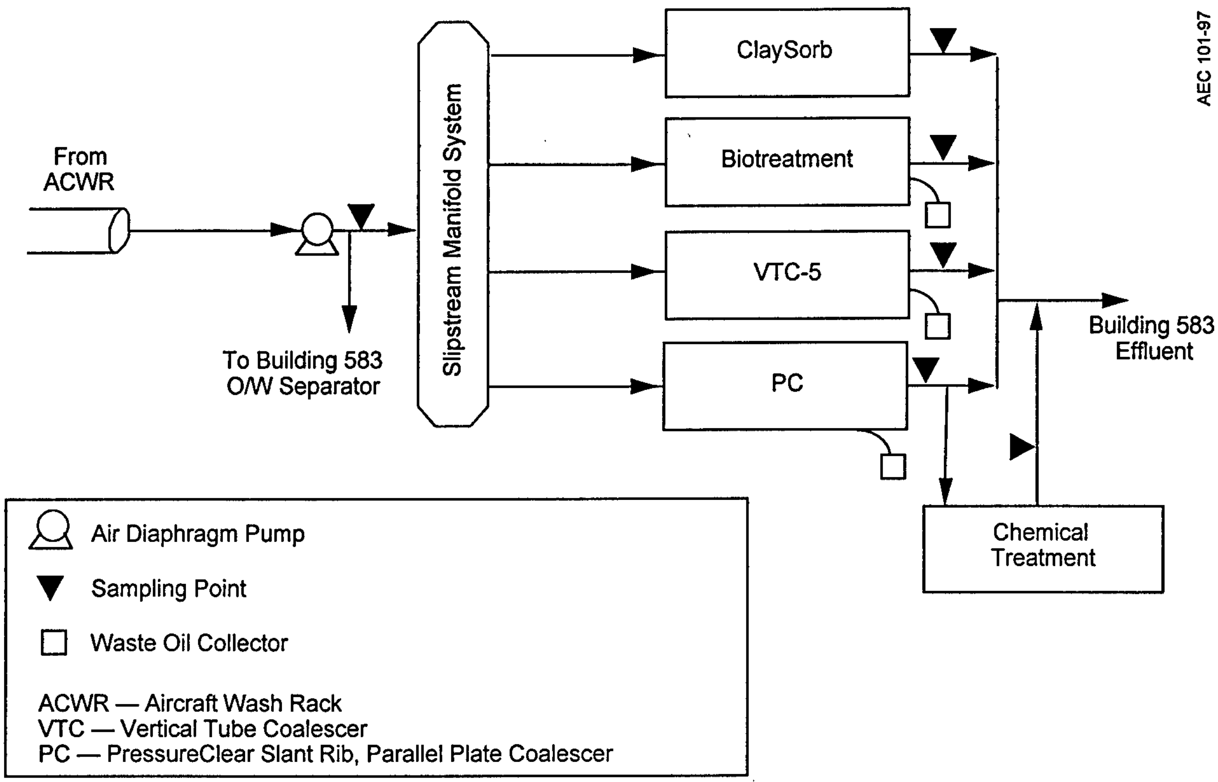

Figure E-2. Influent Wastewater Manifold System Schematic.

TABLE E-1. RESIDENCE TIME AND FLOWRATE SETTINGS FOR THE PRIMARY SEPARATION SYSTEMS.

		Treatment Residence Time (min)			
		30	60	90	120
Unit	Unit Capacity (gal)	Wastewater Flowrate (gpm)			
PressureClear	80	2.7	1.3	0.9	0.7
VTC-5	45	1.5	0.7	0.5	0.4
Biotreatment	45	1.5	0.7	0.5	0.4
Baseline SGS	75	2.5	1.3	0.8	0.6

TABLE E-2. TEST PROGRAM AVERAGE INFLUENT WASH-WATER STREAM O&G CONCENTRATION.

Sample	Average Concentration (mg/L)
ACWR discharge stream	50-100
JETC	>500
VWR	>1,000
Lagoon	100
Spike tests	1,200

C. SAMPLING PROCEDURES

Influent wastewater and treated water samples from the test units were collected for analysis. Figure E-2 is a schematic of the influent wastewater manifold system and the influent and effluent sampling locations. Influent samples were collected from a sampling valve on the manifold. Effluent from each of the test units was collected at the discharge of the unit.

Samples for O&G analysis were collected in 1-L wide-mouth glass jars with air-tight screw-cap lids. Samples for TOC and COD analyses were collected in 40-mL glass vials provided by the offsite laboratory that performed these analyses. Samples for surfactant analysis (MBAS) were collected in 500-mL plastic containers, also provided by the offsite laboratory.

As soon as they were collected, all samples were labeled and logged into a sample logbook located at the test site in Building 583. After the samples were logged at the test site, they were transported to the onsite laboratory for analysis or shipment to the offsite laboratory. Standard ARCADIS Geraghty & Miller chain-of-custody procedures were followed for all offsite shipments.

D. ANALYTICAL PROCEDURES

The analytical measurements performed in this test program can be classified as either critical or noncritical measurements. More-rigorous quality assurance (QA) procedures were adopted for the critical measurements. As a consequence, the total

number of samples analyzed for critical parameters was significantly greater than the number analyzed for the noncritical parameters, in part because of the additional QA samples (duplicates and spikes, for example) analyzed. Table E-3 gives a summary of the specific analytical procedures used. The following subsections describe each of the procedures in more detail.

TABLE E-3. TEST PROGRAM ANALYTICAL PROCEDURES.

Analysis	Method
Critical Analysis	
Oil and Grease (O&G)	Modified EPA Method 1664
Non-Critical Analyses	
Total Organic Carbon (TOC)	EPA Method 415.2
Chemical Oxygen Demand (COD)	EPA Method 410.4
Anionic Surfactants	MBAS
Quantity of Filterable Solids (QFS)	Gravimetric

1. Oil and Grease (O&G) by EPA Method 1664

O&G analyses of test samples were performed using EPA Method 1664.[E-1] This method measures n-hexane extractable material (HEM) and silica-gel-treated hexane extractable material (SGT-HEM) by extraction and gravimetry. This method has not yet been promulgated by the EPA. Figure E-3 shows the Method 1664 setup at the onsite laboratory.

The method can be summarized as follows. A sample of no more than 1 L is collected and acidified to a pH of less than 2. The sample is emptied into a separatory beaker connected to a vacuum manifold. The vacuum is used to pull the sample through a glass filter, an activated extraction disk, and a metal screen filter. O&G is collected on these filters. The extraction disk is dried, and the disk and its drying container are triple-rinsed with hexane. The hexane rinsate is passed through the extraction disk and a sodium sulfate drying cartridge, and collected in a clean, weight-tared 40-mL glass vial. This vial, containing the hexane-extracted O&G, is placed in a

warm water bath (20° to 25°C) and air dried. After the vial is air-dry, it is weighed and placed in a desiccator for at least 12 hours, then desiccated to constant weight. The QA procedures employed included proper instrument calibration, matrix spike (MS)/matrix spike duplicate (MSD) sample preparation and analysis, water blank sample analysis, and blank spike sample preparation and analysis.

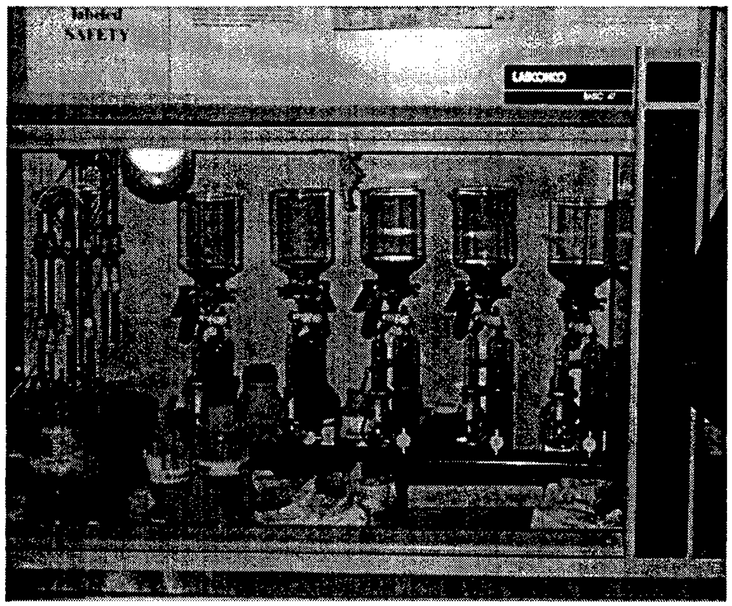

Figure E-3. EPA Method 1664 Onsite Analytical Setup.

Several problems were encountered in applying this method in the test program. These included:

- Evidence that trace quantities of O&G adhered to the glassware of the sample container and extracted beaker in some cases, despite the hexane triple rinse
- Occasional passage of sodium sulfate fines from the drying tubes into the glass extract collection vial
- Routine formations of a precipitate when the method-recommended spiking standard, a mixture of hexadecane and stearic acid in acetone, was added to the local tap water
- Routine poor spike recoveries from MS/MSD samples

With respect to the spiking standard precipitation problem, the recommended spiking solution for Method 1664 is a mixture of equal amounts of hexadecane and stearic acid in acetone. A standard spike solution was obtained from the supplier of the Method 1664 apparatus. Early in the testing, it was discovered that the local tap water had a high hardness level (82 ppm), which gave rise to the precipitate when the spiking solution was added. Suspicions were that the precipitate formed was composed of salts of stearic acid. As no alternative standard was available from the supplier, one was prepared onsite. This new standard was prepared by mixing acetone and Havoline™ brand motor oil, then decanting the acetone layer after separation. The decantate was measured for O&G content and used as the new spiking solution.

Another concern noted was the uniformly poor spike recoveries from MS/MSD samples. Exploratory tests performed during the initial period of testing suggested that the poor O&G recoveries from MS/MSD samples were likely due to interference from detergents. Therefore, a set of experiments was performed onsite to investigate the effect of detergent concentration on recovery from MS/MSD samples. Table E-4 summarizes the results of these experiments. As shown in Table E-4, spike recoveries were acceptable for blank samples (no detergent). However, in the presence of detergents, spike recoveries were uniformly poor. Despite the poor recoveries, the results in Section 5 of this report are based on as-measured concentrations.

TABLE E-4. RECOVERY OF O&G FROM DETERGENT MATRICES USING METHOD 1664.

Oil Concentration (mg/L)	40	100	200
Detergent: Water	Average Recovery[a] (%)		
0:100	77	82	88
1:100	20	30	51
1:330	40	48	58
1:500	20	22	61
1:1000	35	51	51
Method acceptance criteria	79-114	79-114	79-114

[a]Average computed from triplicate test results.

2. Total Organic Carbon (TOC) by EPA Method 415.2

TOC was determined by EPA Method 415.2. The method involves treating samples with acidified persulfate, followed by a standard purge and trap, with flame ionization detector (FID) analysis of the organic content. Samples were analyzed offsite by a commercial laboratory. All samples were collected, preserved, and shipped according to the method requirements.

3. Anionic Surfactants as Methylene Blue Active Substances (MBAS)

Detergent concentrations in washwater samples were estimated by performing analyses for anonic surfactants using the MBAS technique. A dye, methylene blue, in aqueous solution reacts with anionic-type surface active materials to form a blue-colored salt. The salt is extractable with chloroform, and the intensity of color produced in the chloroform extract is proportional to its MBAS concentration.

4. Chemical Oxygen Demand (COD) by EPA Method 410.4

EPA Method 410.4, COD by colorimetric analysis, was used to determine the COD in selected samples. Samples for COD analysis were collected in duplicate in 40-mL glass vials and acidified with sulfuric acid to a pH of less than 2. The samples were kept refrigerated at less than 4°C prior to shipment, and were shipped packed in ice. At the analytical laboratory, the samples were treated with a digester solution (potassium chromate, sulfuric acid, and mercuric sulfate) and a catalyst solution (silver sulfate and sulfuric acid), mixed, and baked in a block digester at 150°C for 2 hours. Once cooled, the color intensities of the samples were measured and compared with those of the standards solutions.

5. Suspended Solids as the Quantity of Filterable Solids (QFS)

Samples of primary treatment process discharge treated with the coagulant and flocculant for chemical demulsification contained a floc at the bottom of the sample containers. The weight of the floc was determined by standard gravitational methods as follows. The floc was filtered, using a Whatman #40 filter paper, from a known volume of sample. The filter and floc were then desiccated to constant weight.

REFERENCE FOR APPENDIX E

E-1. "Method 1664: N-Hexane Extractable Material (HEM) and Silica Gel Treated N-Hexane Extractable Material (SGT-HEM) by Extraction and Gravimetry (Oil and Grease and Total Petroleum Hydrocarbons)," EPA-821-94-004b, Office of Water Engineering and Analysis Division (4303), Washington, DC, April 1995.

APPENDIX F
VENDOR DESCRIPTIONS

- Appendix F-1: Slant Rib Coalescing Oil/Water Separator Model SCR-M (Great Lakes Environmental Inc.)
- Appendix F-2: PressureClear (TurnKey Solutions Inc.)
- Appendix F-3: Vertical Tube Coalescing Separator (VTC) (AFL Industries, Inc.)
- Appendix F-4: ROMI-KON™ Oily Wastewater Reduction Machines (Koch Membrane Systems, Inc.)
- Appendix F-5: ClaySorb (TurnKey Solutions Inc.)
- Appendix F-6: Biological Hydrocarbon Digestant (BioSolutions, Inc.)
- Appendix F-7: Chemical Treatment Data (Midwest Custom Chemical Inc.)

Appendix F-1

Slant Rib Coalescing Oil/Water Separator Model SCR-M
(Great Lakes Environmental Inc.)

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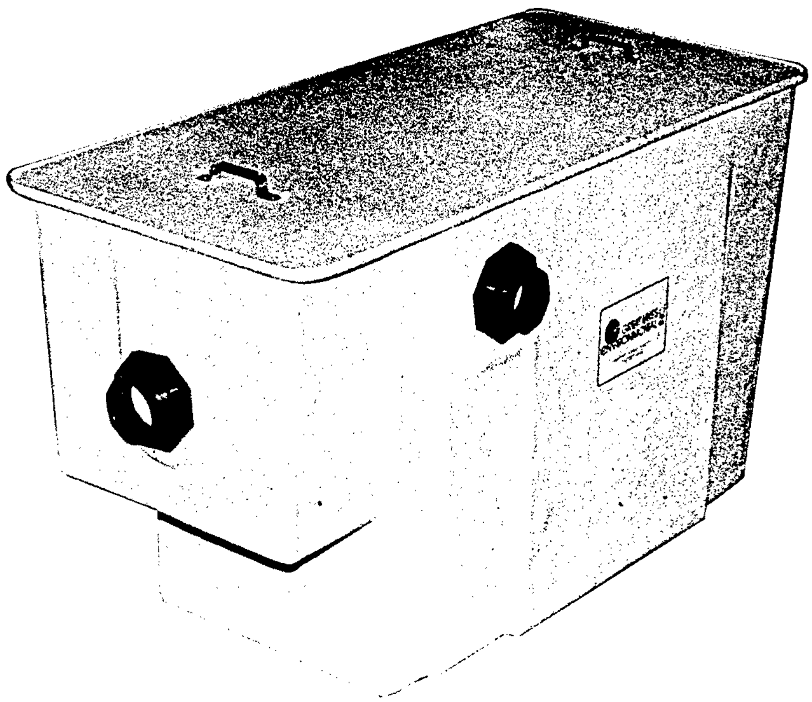
Slant Rib Coalescing Oil/Water Separator Model SRC-M



- *Fiberglass*
- *Efficient*
- *Low Cost*
- *Available From Stock*

PERFORMANCE

The model SRC-M Slant Rib Coalescing Oil/Water Separator will continuously remove essentially all non-emulsified oil from waste water containing minimal solids, and produce an effluent with less than 10 mg/l of oil droplets larger than 20 microns. After separation, the oil and water discharge through individual nozzles.

OPERATION

The SRC-M is manufactured as a single piece, molded polyester fiberglass unit with special baffles and weirs to direct flow, skim oil and control liquid levels in the separator. The slant rib coalescing media is oleophilic (oil attracting) and has an efficient sinusoidal flow pattern to promote impingement of the oil droplets on the media surface. The oil coalesces and rises to the surface of the separator where the oil is automatically decanted by an adjustable skimmer.

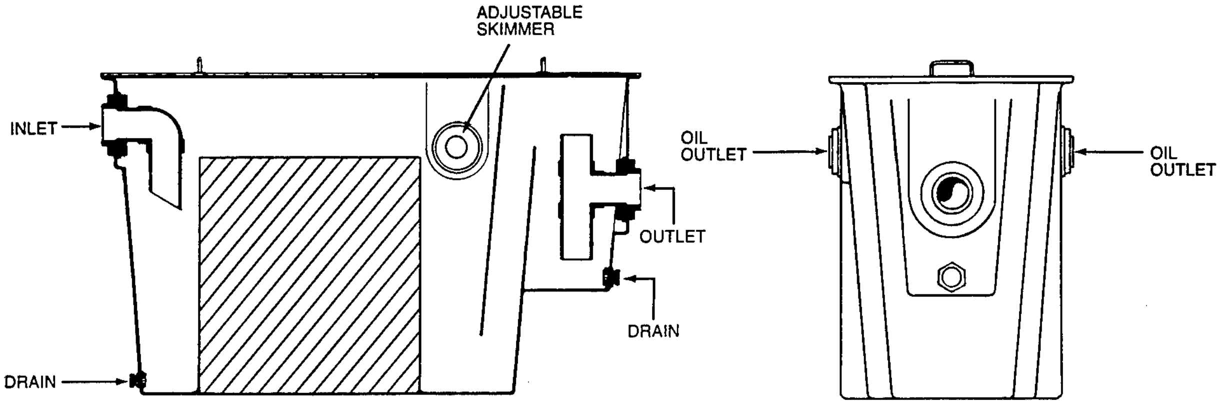
APPLICATIONS

- ☐ Surface skimmings
- ☐ Ponds
- ☐ Wash tanks
- ☐ Rinse tanks
- ☐ Sumps
- ☐ Ground water
- ☐ Condensate
- ☐ Cooling water
- ☐ Floor drains

FEATURES

- Six sizes: 2 to 24 GPM
- Gravity flow
- Leak proof
- Lightweight
- Lift off cover
- Adjustable oil weir
- Clean in place
- Temperature range to 130 F

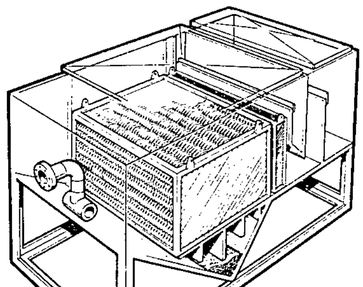
GREAT LAKES ENVIRONMENTAL



DIMENSIONS WEIGHTS & CAPACITIES

Model	Width	Length	Height	Inlet Dia.	Outlet Dia.	Oil Outlet Dia.	Empty Wt. Lbs.	Operating Wt./Lbs.
SRC-M2	1.250′	3.770′	1.833′	1-1/2″	1-1/2″	2″	80	272
SRC-M4	2.166′	3.770′	1.833′	1-1/2″	1-1/2″	2″	120	504
SRC-M6	3.250′	3.770′	1.833′	2″	2″	2″	170	745
SRC-M8	1.250′	4.833′	2.833′	2″	2″	2″	140	907
SRC-M16	2.166′	4.833′	2.833′	3″	3″	3″	200	1735
SRC-M24	3.250′	4.833′	2.833′	3″	3″	3″	260	2562

Dimensions and capacities are for reference only and not to be used for construction.
Model No. represents nominal flow rate in GPM.



NOTE: For continuous or intermittent flows of 15 to 4000 GPM, containing solids that settle, GLE offers the standard model SRC Slant Rib Coalescing Oil/Water Separator in either steel or fiberglass construction. The model SRC offers superior oil removal efficiency, sludge chamber and oil reservoir.

Available Options

- ☐ Dense coalescing pack
- ☐ Oil pump out
- ☐ Sludge pump out
- ☐ Effluent pump out
- ☐ Freeze protection

- 15 standard sizes
- Some models available from stock

GREAT LAKES ENVIRONMENTAL
463 Vista • Addison, IL 60101 • 708-543-9444
FAX 708-543-1169

JBI
3386 TARTAN TRAIL
EL DORADO HILLS, CA 95762
(916) 933-5500

Appendix F-2

PressureClear

(TurnKey Solutions Inc.)

PressureClear

HOW DOES IT WORK?

(PLEASE FOLLOW ALONG ON THE ATTACHED PROCESS FLOW DIAGRAM)

Your wastewater will be collected on a wash pad and directed via a sloped pad or a trench into a collection sump (4' x 4' x4'). We will provide you with a floating skimmer to be mounted in that sump. As the wastewater flows into the sump the heavy solids will drop to the bottom, as they accumulate they should be removed periodically. The free oil will start to float to the top in the sump. When the level reaches the high level switch it will automatically start the influent pump on the PressureClear unit. The influent pump will draw the water and free oil from the sump and pump it into the coalescing oil/water separator.

In the separator, additional solids will settle into the sludge chamber and all free oil (droplets 20 microns and larger) will float to the top and be skimmed off. The "gray water" will flow out of the unit into a transfer reservoir. This gray water still contains emulsified oil (droplets smaller then 20 microns) and fine suspended solids. As the transfer reservoir fills up, the discharge pump will turn on and pump the water through two bag filters for final polishing. The first filter will remove solids down to 25 microns. The second filter is designed to absorb emulsified oil.

The PressureClear Solution

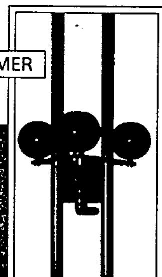
How It Works:

Your wastewater can be collected in a sump or a tank. Heavy solids can be settled for periodic removal. The influent pump on the PressureClear unit will automatically pump the water into the oil/water separator which will remove free oil and additional settleable solids.

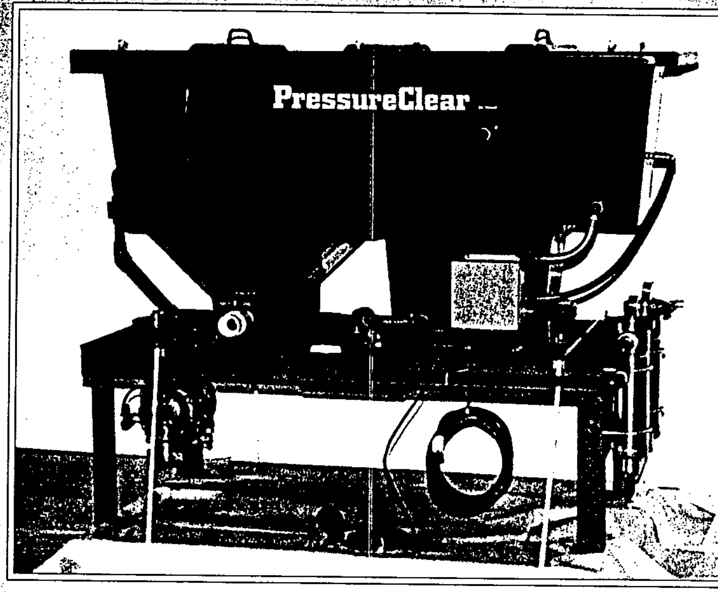
The "gray water" from the separator flows into a transfer reservoir, from there, a booster pump automatically pumps the water into one or more of the post-treatment modules.

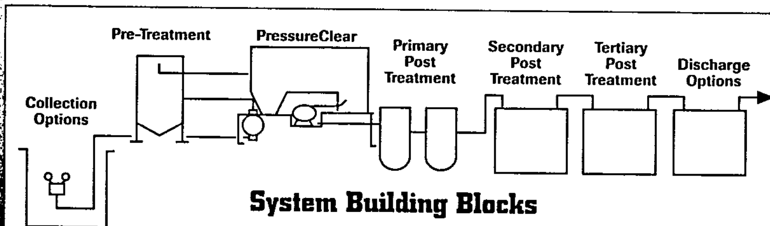
Pre-Treatment Options:

- Floating Skimmer
- Equalization Tank
- Biological
- pH Adustment
- Sludge Pump



FLOATING SKIMMER





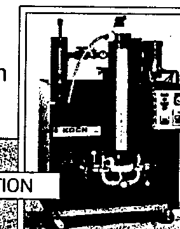
System Building Blocks

The Flexible Solution:

TurnKey Solutions has designed and constructed numerous industrial wastewater treatment systems. Now we have taken that wealth of experience and designed a modular, pre-engineered, skid built, waste water treatment system. The system is modular so that you only need to purchase the components that address your specific problem! The system is pre-engineered so that you do not have to incur the expense of a custom designed system! The system is skid built so that the installation is quick and inexpensive!

Post-Treatment Options:

- Bag Filter for Suspended Solids
- Bag Filter for Emulsified Oil
- Ultrafiltration
- Biological
- Carbon
- ClaySorb
- Lift Station
- Recycle



ULTRAFILTRATION

Appendix F-3

Vertical Tube Coalescing Separator (VTC)

(AFL Industries, Inc.)

AFL industries, inc.
3661 west blue heron blvd.
riviera beach, florida 33404
(407) 844-5200 FAX (407) 844-5246

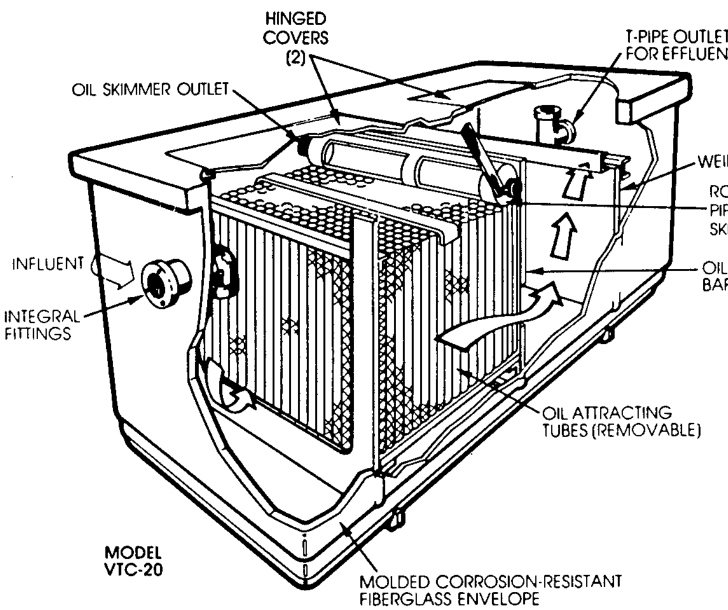
PRIMARY TREATMENT

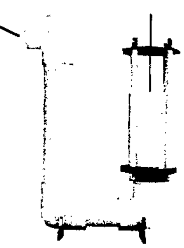
Vertical Tube Coalescing Separator (VTC)*
20, 50 GPM

FUNCTION:
REMOVES FREE OILS, NON-PERMANENT MECHANICALLY EMULSIFIED OILS, SETTLEABLE SOLIDS

PRODUCT BULLETIN

NO. 2-10.B.1





OIL STOP VALVE
(Optional)

Can reduce oil content of wastewater down to 10 mg/ltr
Removes up to 99% of tramp oil from coolant
Inherent insulation, less than 1.0 U factor (heat transfer)
Corrosion-resistant fiberglass tank
Pre-engineered, prepackaged, ready to install
Self-contained, no power source required.
Precision sizing: 20, 50 gpm

AFL's VTC 20, and 50 remove hydrocarbons from wastewater and tramp oils from machine tool coolant. A precisely-engineered coalescing medium in the VTC enhances the gravity separating process.

The coalescing material, a matrix of oleophilic (oil-attracting) tubes, intercepts oil globules of all sizes. As globules coalesce on the tubes, they increase in size and buoyancy, finally breaking away to rise through the tubes to the top. Surface oil drains by gravity into an integral rotary pipe skimmer and then flows to external storage.

Performance that can be expected of the VTC separator is:

(1) removal of oil globules down to 20-micron size.
(2) reduction of oil content to 10 mg/ltr.

The VTC removes even non-permanent mechanically emulsified oil. It leaves no visible sheen and traps solids too. In metalworking and similar applications, it removes up to 99 percent of tramp oils from coolants.

Improved oil-separating efficiency means packaging in a smaller envelope. Completely corrosion-resistant, the separator is molded of fiberglass and equipped with PVC piping. It comes pre-engineered, prepackaged, ready to install.

The entire exterior surface of the fiberglass tank is covered with corrosion-resistant gelcoat, integrally-colored and ultra-violet resistant. Since the envelope and fittings (PVC) are corrosion-resistant, the separator can be installed in many hostile environments. No sacrificial cathodic protection is required.

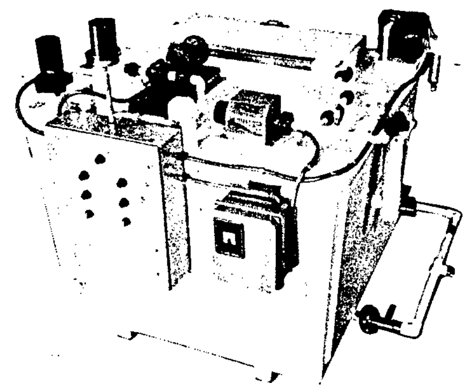
Equipment and construction options are available. These include heater packages, automated sludge removal, product pump-out systems, and special resins or steel construction.

*Patented

VTC OPTIONS

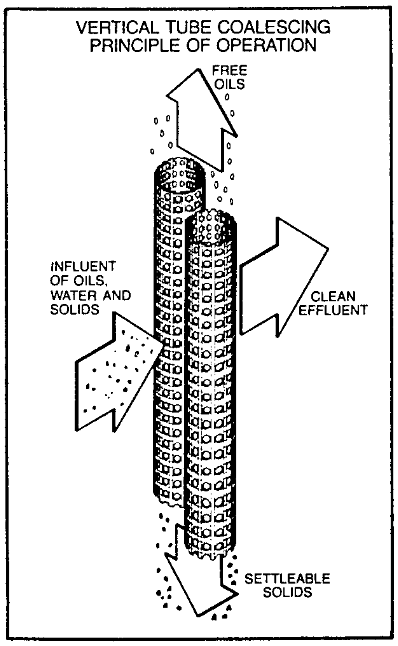
Heating Systems
  Electric (Bull. 10-05.B.1)
Height Extension
Ladders and Hand Rails
Level Switches
Oil Storage
  Built-in
  Separate tank
Piping
  PVC Std.
  CPVC
  FRP

Pump-out System
  Effluent (Bull. 9-20.B.1)
  Product (Bull. 9-15.B.1)
  Sludge (Bull. 9-25.B.1)
    electric
    air
Special resins for FRP construction
Special coating for steel construction

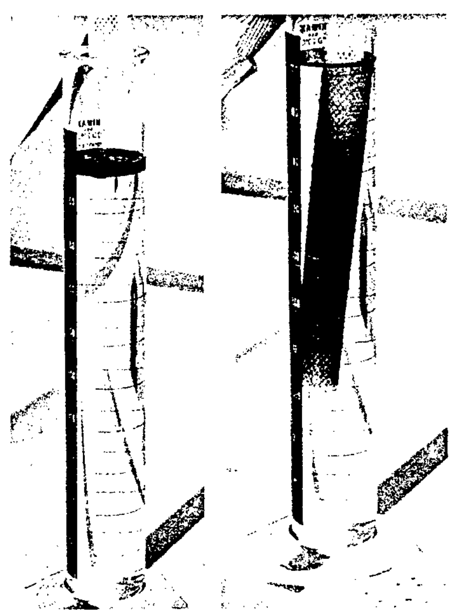


VTC-20A2 with options

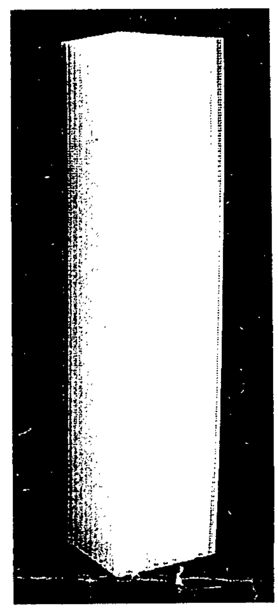
TUBES REMOVE OIL



Tubes reduce free oil content of effluent down to 10 mg/ltr or less because microscopic oil particles agglomerate on the surface. The growing oil globules, when sufficiently buoyant, break free to rise to the surface.



A single pass of a perforated tube used in the VTC demonstrates the oleophilic (oil-attracting) properties of the material. These photos show the reverse of separator operation, where contaminated water moves past a battery of tubes.



Tubes for the VTC are welded in one-foot square bundles (as above). These bundles, held in place by a cradle, can easily be lifted out individually for inspection.

AFL industries, inc.
3661 west blue heron blvd., riviera beach, florida 33404 (407) 844-5200 FAX (407) 844-5246

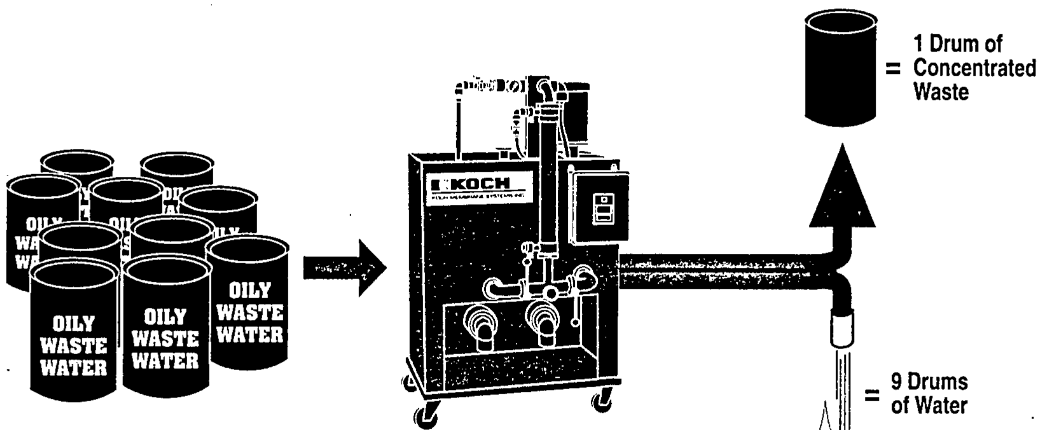
Appendix F-4

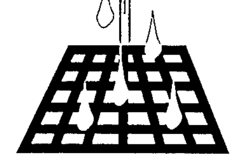
ROMI-KON™ Oily Wastewater Reduction Machines

(Koch Membrane Systems, Inc.)

ROMI-KON™
OILY WASTEWATER REDUCTION MACHINES

Reduce Spent Coolant	Reduce Parts Washer Effluent	Reduce Air Compressor Condensate	Reduce Mop Water





REDUCE OILY WASTEWATER VOLUME BY 90%

The ROMI-KON™ machine reduces oily wastewater produced from spent coolants, parts washer baths, air compressor condensate, and mop water by 90%.

The ROMI-KON™ machine is mobile, compact, low cost, and economical to operate. This oil-water emulsion separator allows you to save money by reducing hauling and disposal costs 10 to 1.

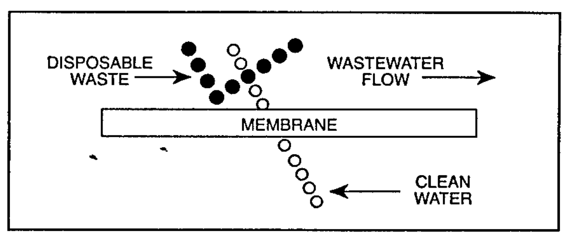
The ROMI-KON™ machine is easy to operate and requires minimal maintenance. Simply fill the process tank with oily wastewater and start the process pump. Immediately you will begin to reduce the wastewater volume and produce clean water. In most cases, the clean water will meet local discharge limits, but check with your local authority to be sure. The other option is to recycle this clean water elsewhere in the plant for additional cost savings.

The ROMI-KON™ machine uses a hollow fiber ultrafiltration membrane to separate the oily waste from the clean water. The use of crossflow hollow fiber technology maximizes the life of the membrane.

When the flow of clean water decreases, the membrane surface is easily and quickly cleaned by circulating a cleaning solution from the attached cleaning tank. This simple cleaning procedure extends the life of the membrane. The spent cleaning solution is then processed with the next batch of waste.

Basic Membrane Technology

Membrane technology is simple. The membrane separates the wastewater into two streams. One contains concentrated disposable waste and the other contains clean water.

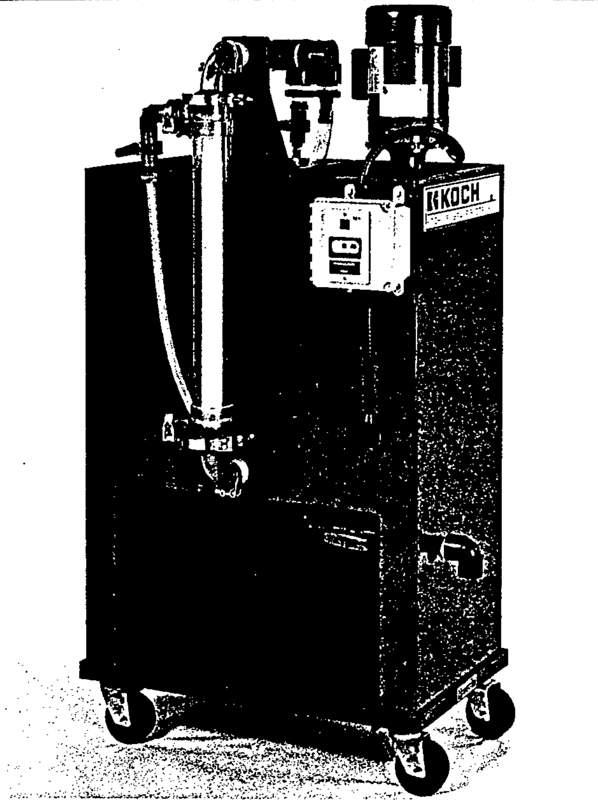


ROMI-KON™ Benefits

- Low cost
- Simple to operate
- Rugged construction
- Made in the U.S.A.
- Consistent, high quality effluent
- Reduce hauling costs

KOCH
KOCH MEMBRANE SYSTEMS INC

ROMICON®
Abcor®

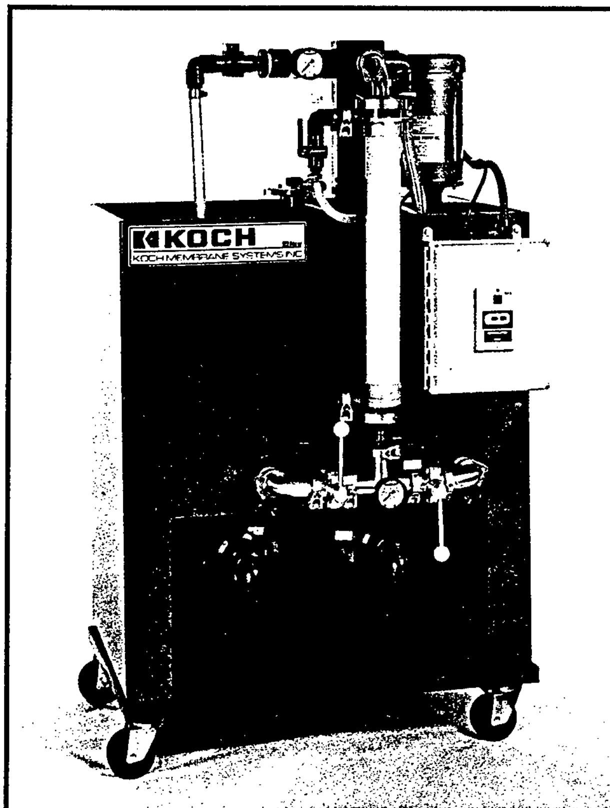


ROMI-KON™ 50

(Daily capacity = 50 gal./24 hr. day)

- Overall dimensions .... 33"L x 26"W x 57"H
- Operating temperature .... 50-113° F
- Prefiltration (included) .... 100 micron
- Process tank capacity - max .. 40 gal.
- Cleaner tank capacity - max .. N/A
- Process pump
  - capacity .... 10 gpm @ 25 psi
  - hp 1.0
  - rpm 3500
  - amps 11.5
- Power required .... 115V, 1Ø, 60 Hz*, 15A
- Wetted material .... polypropylene, 304ss, viton or equivalent
- Controls .... motor starter with run light, low-level switch
- Shipping weight .... 125 lbs.

*50 Hz available



ROMI-KON™ 100

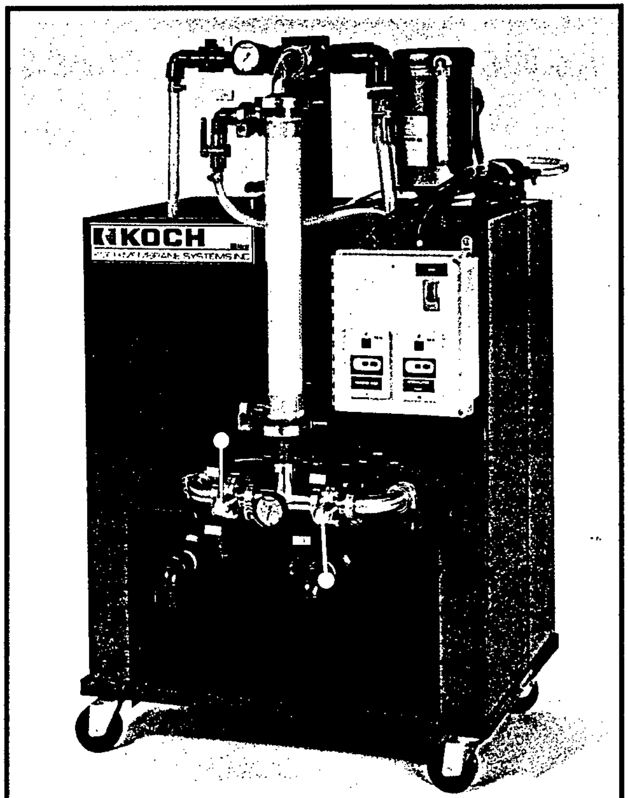
(Daily capacity = 100 gal./24 hr. day)

- Overall dimensions .... 36"L x 34"W x 60"H
- Operating temperature .... 50-113° F
- Prefiltration (included) .... 100 micron
- Process tank capacity - max .. 50 gal.
- Cleaner tank capacity - max .. 15 gal.
- Process pump
  - capacity .... 30 gpm @ 25 psi
  - hp 1.0
  - rpm 3500
  - amps 11.5
- Power required .... 115V, 1Ø, 60 Hz*, 15A
- Wetted material .... polypropylene, 304ss, viton or equivalent
- Controls .... motor starter with run light, low-level switch
- Shipping weight .... 225 lbs.

*50 Hz available

Koch offers equipment to process larger volumes of wastew

ON™ Features

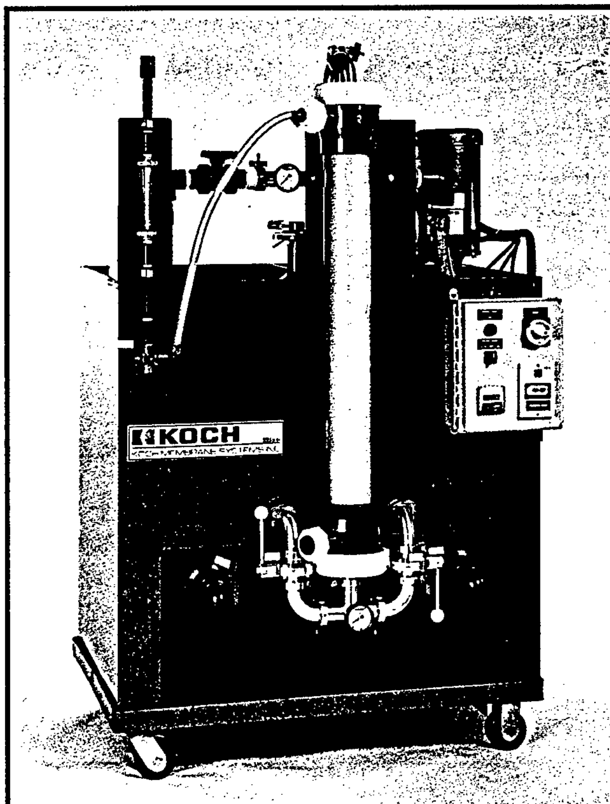


ROMI-KON™ 300

(Daily capacity = 300 gal./24 hr. day)

■ Overall dimensions	36"L x 34"W x 60"H
■ Operating temperature	50-113° F
■ Prefiltration (included)	100 micron
■ Process tank capacity - max.	50 gal.
■ Cleaner tank capacity - max.	15 gal.
■ Process pump	
capacity	30 gpm @ 25 psi
hp	1.0
rpm	3500
amps	11.5
■ Transfer pump	
capacity	3.5 gpm @ 20 psi
hp	1/8
amps	1.5
■ Power required	115V, 1Ø, 60 Hz*, 20A
■ Wetted material	polypropylene, 304ss, viton or equivalent
■ Controls	motor starters with run lights, low-level switch, automatic on/off level switch for transfer pump
■ Shipping weight	250 lbs.

*50 Hz available



ROMI-KON™ 1000

(Daily capacity = 1000 gal./24 hr. day)

■ Overall dimensions	43"L x 40"W x 68"H
■ Operating temperature	50-113° F
■ Prefiltration (included)	100 micron
■ Process tank capacity - max.	80 gal.
■ Cleaner tank capacity - max.	30 gal.
■ Process pump	
capacity	62 gpm @ 25 psi
hp	2.0
rpm	3500
amps	11.5
■ Transfer pump	
capacity	3.5 gpm @ 20 psi
hp	1/8
amps	1.5
■ Power required	230V, 1Ø, 60 Hz*, 20A
■ Wetted material	polypropylene, 304ss, viton or equivalent
■ Controls	motor starters with run lights, low level switch, automatic on/off level switch for transfer pump, flowmeter.
■ Shipping weight	300 lbs.

*50 Hz available

wastewater. Whatever the need, Koch has the right machine.

COST SAVINGS PER YEAR

Gallons per month	Waste Hauling Costs in $ per gallon: $0.25	$0.50	$1.00	$2.00	$3.00
200	$540	$1,080	$2,160	$4,320	$6,480
400	$1,080	$2,160	$4,320	$8,640	$12,960
600	$1,620	$3,240	$6,480	$12,960	$19,440
1,000	$2,700	$5,400	$10,800	$21,600	$32,400
1,500	$4,050	$8,100	$16,200	$32,400	$48,600
2,000	$5,400	$10,800	$21,600	$43,200	$64,800
5,000	$13,500	$27,000	$54,000	$108,000	$162,000
10,000	$27,000	$54,000	$108,000	$216,000	$324,000
20,000	$54,000	$108,000	$216,000	$432,000	$648,000

*Based on a 90% reduction in wastewater volume.

Koch Membrane Systems is an established world leader in crossflow membrane technology continually setting industry standards. Koch manufactures under the registered trademarks Abcor and Romicon. Koch offers over a quarter century of experience in supplying industry with innovative filtration solutions and can help solve most wastewater treatment problems.

AGENTS, REPRESENTATIVES, AND DISTRIBUTORS AROUND THE WORLD

KOCH
KOCH MEMBRANE SYSTEMS INC

ROMICON®
Abcor®

Koch Membrane Systems, Inc.
850 Main Street
Wilmington, MA 01887
TEL 508-657-4250
800-343-0499 (in U.S.)
FAX 508-657-5208

Koch Int'l B.V.
Mechelaarstraat 14
4903 RE Oosterhout (DB)
The Netherlands
TEL 31-1620-32052
FAX 31-1620-52494

Koch Int'l GmbH
Membrane Systems Division
Neusser Strasse 33
D-40219 Duesseldorf 1
Germany
TEL 49-211-90195-0
FAX 49-211-394278

Koch Int'l S.A.R.L.
ABCOR Division
Centre Daumesnil
4 Place Felix Eboue
75583 Paris Cedex 12
France
TEL 33-1-400-48656
FAX 33-1-400-48658

Koch Int'l U.K. Limited
Friars Mill
Friars Terrace
Stafford
Staffs ST17 4Au
England
TEL 44-785-212565
FAX 44-785-223149

1-94/5K
PN 0679174

Appendix F-5

ClaySorb

(TurnKey Solutions Inc.)

TURNKEY

SOLUTIONS INC.

CLAYSORB

OIL/WATER SEPARATION MEDIA REMOVES EMULSIFIED OIL FROM WATER

EFFICIENTLY!

PROJECT MANAGEMENT, INSTALLATION & START-UP

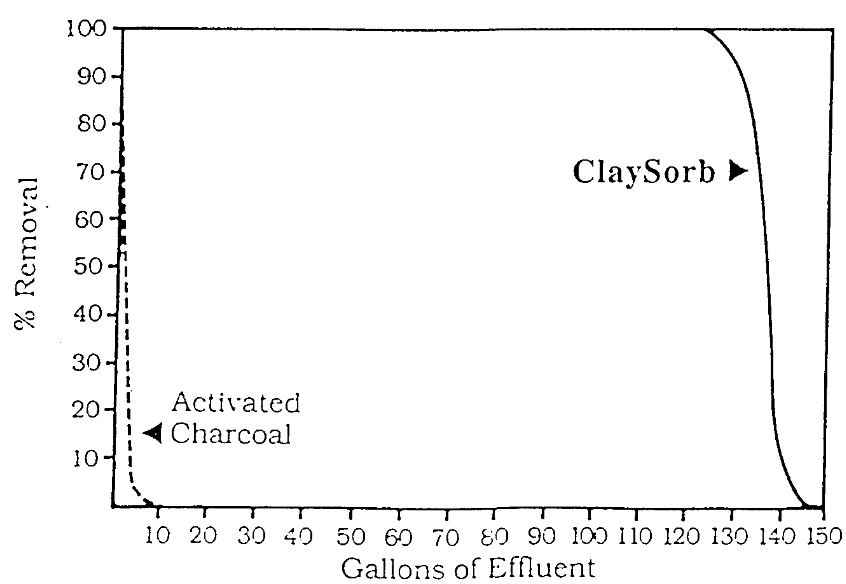
TURNKEY
SOLUTIONS INC.

CLAYSORB
ORGANICALLY MODIFIED CLAY
EXTENDS THE LIFE OF ACTIVATED CARBON

Removal of Organics from Water

- a COST EFFECTIVE ALTERNATIVE to activated charcoal (G.A.C.)
- ESPECIALLY EFFECTIVE for those organics that are difficult for G.A.C. (i.e., oil, humic acid, etc.)
- GREATER SORPTION CAPACITY than G.A.C. for most organics
- LARGE DYNAMIC RANGE of treatable concentrations (5000 ppm to 1 ppb)

Removal of Oil from Water
Influent Concentration of 50 ppm
Flowrate 1 gpm/ft^2



ClaySorb is a granular, organically modified clay filtration medium for water treatment systems. A blend of bentonite and anthracite treated with a quaternary amine, ClaySorb removes mechanically emulsified oil and grease, large molecular weight chlorinated hydrocarbons, and heavy metals. And it does it 50% more efficiently than activated carbon.

A cost-saving filtration medium

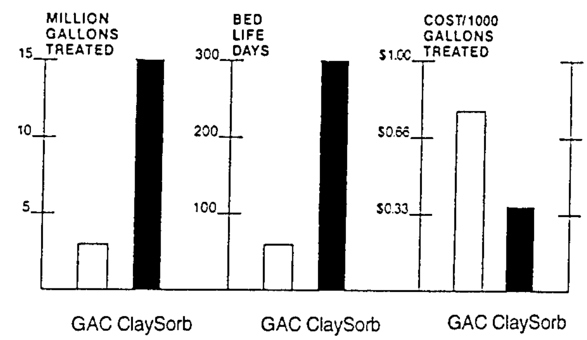
ClaySorb is a highly versatile and effective filtration medium that can be used in pretreatment, post-treatment or stand-alone treatment processes. When used as a pretreatment to carbon in oil and grease removal applications, ClaySorb removes the water soluble organics with up to seven times greater efficiency than carbon filtration alone. Pretreatment with ClaySorb also extends the life of activated carbon by seven times, reducing wastewater treatment cost by 50% or more.

Increased efficiency of activated carbon

The quaternary amine-treated clay platelets in ClaySorb have the ability to capture up to 60% of their weight in oil, grease, and other low solubility organic compounds. Used upstream from activated carbon, ClaySorb removes emulsified oil that would otherwise blind or block the pores of the carbon granules and inhibit their ability to remove more soluble compounds.

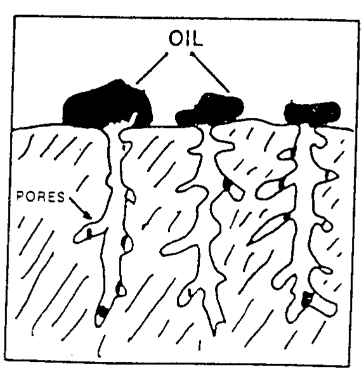
The graph below represents an example of anticipated filter media bed life, and media cost per 1000 gallons of waste water treatment.

Using ClaySorb for removal of mechanically emulsified oil from waste water <u>reduce the treatment cost by 55%.</u>



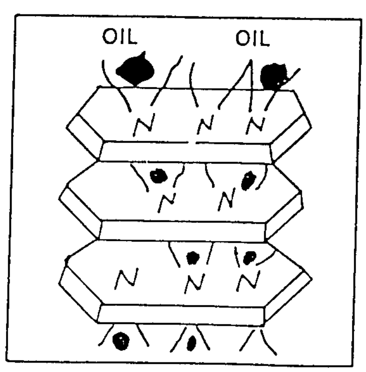
GAC= Granular Activated Carbon

This wastewater stream contains 25 ppm oil and grease, flow rate is 50 GPM during a 10 hour day. Sorption efficiency for oil removal is 50% for ClaySorb and 10% for activated carbon.

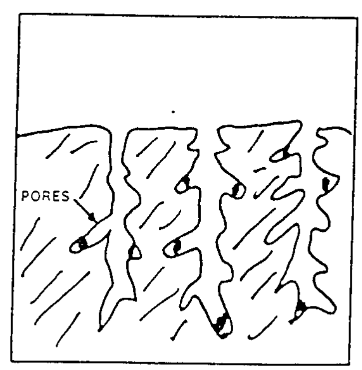


ACTIVATED CARBON GRANULE

Porespaces of activated carbon, blinded by emulsified oil.



Clay Platelets, modified with quaternary amine, remove emulsified oil on the clay surface.



Activated Carbon downstream of ClaySorb, ready to remove the more soluble compounds.

System Design Assistance is Available

ClaySorb can be used in existing pressure filter vessels with proper influent distributors and under drain systems. Expert system design and installation assistance is available to ensure optimal organic waste removal in specific applications. We also offer complete turnkey operations, including not only design and installation, but system servicing an disposal of spent medium, as well.

Spent ClaySorb Disposal is Easy

Disposal options are dependent upon the classification of the organics absorbed. Spent medium can be landfilled, land farmed, incinerated, bioremediated, or blended as a fuel source for firing in cement kilns. Spent ClaySorb has a fuel value of up to 18,000 BTU/lb, depending on the fuel value of the absorbed organics.

Call or Write for More Information

To find out how easy it is to cut the cost of wastewater treatment in half, call or write us today. We'll be happy to answer your questions about ClaySorb and even help you estimate how much you could save by using it in your treatment process.

Applications for ClaySorb

Application	Contaminant Removed
Groundwater Treatment	Diesel fuel, gasoline, oils greases, PCB, BTX, heavy metals
Parts Cleaning	Non-ionic surfacants
Wood Treatment	Pentachlorophenois and creosote
Pigment Production	Organic pigments
Boiler Feed Water	Oil, humic acid, fulvic acid
Gas Sweetening	Large molecular weight hydrocarbons
Dry Cleaning	Perchloroethylene
Drinking Water	Trihalomethanes, heavy metals, hydrocarbons
Electroplating	Heavy metals
Paint Stripping	Solvents, heavy metals
Natural Gas Compression	Condensate
Industrial Stormwater Vehicle and Heavy	Oil and Grease
Equipment Cleaning	Oil and Grease
Produced Water from Oil Production Wells	Oil, diesel fuel

CLAYSORB

Organically modified clay filtration medium

Specifications

U.S. Mesh Size	8 x 30
80% passes through	No.8
5% or less passes through	No. 50
Water Retention, drained	10%
Moisture:	8% or less
Density	
Shipped	61 lb/ft3
Backwashed, settled in column	50-57 lb/ft3

Design Criteria

Bed Depth:	3 ft. Min.
Hydraulic Loading:	2-5 gpm/ft2 max.
Contact Time:	15 min. recommended
Bed Expansion (during back wash)	20%
Standard Packaging:	55 gal drum or bulk bags

Filter Design Features

Appropriate underdrain to ensure uniform water flow throughout the bed of ClaySorb to prevent channeling.

Support bed over underdrain (sand, gravel, anthracite, etc.)

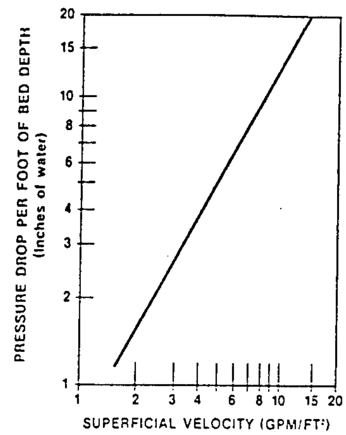
Adequate freeboard to allow for bed expansion if backwashed.

Air eliminator.

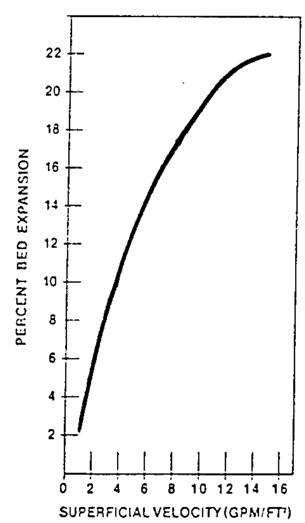
Access to mechanical vacuum of spent ClaySorb.

Distributor or splash plate.

Downflow pressure drop throug a backwashed column of ClaySorb (80°F)



Percent bed expansion during backwashing of ClaySorb (80°F)



Appendix F-6

Biological Hydrocarbon Digestant
(BioSolutions, Inc.)

BIOLOGICAL HYDROCARBON DIGESTANT

BioSolutions' bacteria have the capacity to degrade the full spectrum of hydrocarbons, including refined petroleum products, by-products, and waste. Among materials routinely treated by BioSolutions' proven methods are the following:

Benzene, toluene, ethylbenzene, xylenes (BETH compounds)
Naphthalene and other polycyclic aromatic hydrocarbons (PAHs)
Jet fuel and kerosene
Creosote, Fuel oil and Refinery wastes
Lubricating and cutting oils
Oil tar and coal tar
Chlorinated solvents
All organic waste
Specialty compounds and chemicals

The degradation of hydrocarbons is a little more complex due to the variety of the compounds found in oil and gas, but it is based on the same principle as grease trap remediation. From our viewpoint, the easiest pollutants to clean up are oils and gasoline. The most important factors to consider when evaluating a site for cleanup are:

1. Contaminant and concentration.
2. Availability of water and oxygen.
3. Availability of additional nutrients such as nitrogen and phosphorous.
4. Temperature.
5. Ability of bacteria to interact with contaminant and nutrients.
6. Presence of antibacterial compounds such as heavy metals.

BioSolutions has developed a series of products which are based on specialized strains of microorganisms to treat the wide spectrum of hydrocarbon contaminants. Typically, the laboratory will define the proper mix to optimally digest the contaminants based on the results of the analysis. The introduction of microorganisms at the source of contamination serve to accomplish two desired outcomes; cleaning the ducts and the oil water separators of hydrocarbon contamination. Also, in those unique situations such as military installations, hydrocarbon microorganisms may be introduced into the sewer lines in base housing to digest hydrocarbon contaminants to include phenols. By doing so, the net effect is elimination of contamination into the main sewerage lines and consequently, reduced cost and elimination of liability to the customer since there is no contaminants to be removed to a landfill. The need to clean the silt and dirt from the oil water separator still exists; however, the frequency is reduced dramatically and since it is clean, it can be disposed of at the local landfill or used on the premises.

The product is introduced to the affected system in a liquid form. It is dispensed daily from a peristaltic pump attached to two containers; one with product and the second with

6 Stratton Drive, West Borough, MA 01581 1(800)240-2400 FAX:1(508)366-6568
2156 Sandell, Grapevine, TX 76051 1(800)232-5584 FAX:1(800)335-5584
email:BioSolutions@MSN.Com

nutrient, in sufficient quantity to create a colony of ample size to digest the hydrocarbon contaminant in the oil water separator and drain lines. The timer on the pump is set to dispense the product and nutrient at selected set intervals each day to optimize the introduction of the microorganisms to the system based on temperature and activity in the system. Generally, the pump is connected to 110 VAC; however, if electricity is not accessible, the pump may be battery operated. The feed line from the pump is either tapped into the drain line from a sink or placed in the drain leading from the sink to the oil water separator. As the microorganisms proceed through the drain lines, a portion will also digest any contaminants collected on the walls. Oxygen is a significant factor in the remediation process. Consequently, we often times will complement the oxygen in the water with supplemental air through an aerator which has enhanced our success even in the most difficult separators where the hydrocarbon contaminant level is very high. The pumps require 110 VAC to operate. The tanks provided to supply the product may be configured to be re-supplied every 30-60 days.

Once the bacteria have been introduced, it is important to follow the degradation of the pollutant, which involves analysis of the water and/or soil being treated. This can be accomplished in many ways including testing for total oil and grease, total recoverable petroleum hydrocarbons (TRPH), volatile organic compounds (VOC), and polyaromatic hydrocarbons (PASs). One very important aspect of testing is the collection of samples for testing. The samples to be analyzed must be representative of the sites and must be taken on a regular schedule. There is no point in doing analytical work on a sample if the sample is not acceptable.

SUMMARY

Bioremediation, as a process, is not high technology. We may have to employ some high tech application to correct a problem; however, its purpose is strictly to accomplish our fundamental objective; create a colony of sufficient size and proper bacteria to sustain the effort of digesting the bacteria being introduced from its source. Our focus is on achieving this fundamental goal at the lowest possible cost to you the customer. We achieve this through our extensive experience and studies of your sites. The process is an ongoing effort simply because the introduction of contaminants is ongoing.

Once we have an established colony, remediation keeps the system clean, eliminating the smell and secondly reducing the possibility for health problems. Finally, the requirement to clean the traps and separators is reduced dramatically to only removing the inorganic materials. And since the material has been exposed to the colony, it too will be clean and may be disposed of in any landfill. We ask that you consider our process and evaluate it on a for sixty days. We firmly believe that the test results will convince you, as it has our other customers, bioremediation is the most cost effective method to assist you with achieving your environmental goals. The results will speak for themselves.

6 Stratton Drive, West Borough, MA 01581 1(800)240-2400 FAX:1(508)366-6568
2156 Sandell, Grapevine, TX 76051 1(800)232-5584 FAX:1(800)335-5584
email:BioSolutions@MSN.Com

We are constantly evaluating the products being introduced to the market through rapid biotechnology advances. It is through our constant search for better processes and products as well as our willingness to work as a partner with our customer to select a solution that we have been able to develop our credibility.

6 Stratton Drive, West Borough, MA 01581 1(800)240-2400 FAX:1(508)366-6568
2156 Sandell, Grapevine, TX 76051 1(800)232-5584 FAX:1(800)335-5584
email:BioSolutions@MSN.Com

MATERIAL SAFETY DATA SHEET

Section I Identification

Product Name:	Custom HC
Chemical Name:	N/A
Formula:	Natural Microbial Cultures (Type R-5) Chemical Family: N/A

Department of Transportation
Hazardous
Classification: None

Section II Physical/Chemical Characteristics

Boiling Point:	100 degrees Centigrade
Vapor Pressure (mm Hg.)	Water
Vapor Density (air=1)	Water
Solubility in Water:	N/A

Specific Gravity: (Water=1): One
Evaporation Rate (Butyl Acetate=1): Water
Appearance & Odor: Tan w/ slight Organic Odor (May contain dyes)

Section III Fire and Explosion Hazard Data

Flash Point:	N/A
Extinguishing Media:	Water

Flammable Limits: N/A
Special fire fighting Procedures: None

Section IV Reactivity Data

Stability:	Unstable or Stable
Conditions to Avoid:	Excessive heat, strong acids or bases, and bacterial compounds
Incompatibility:	Not compatible with strong acids or bacterial compounds
Hazardous Decomposition:	N/A
Hazardous Polymerization:	N/A

Section V Spill or Leak Procedures

Leak and Spill Procedure:	Comply with local, state, and federal regulations
Waste Disposal Method:	Bio-remedial and safe; comply with local state and federal regulations

Section VI Special Protection Information

Respiratory Protection:	None required
Protective Gloves:	None required
Eye Protection:	None required
Clothing:	No special requirement

Section VII Spill or Leak Procedures

Steps to be taken in Case Material is released or spilled:	Comply with local, state, and federal regulations
Waste Disposal Method:	Comply with local, state, and federal regulations

Section VIII Health Hazard Data

Threshold of Limit Data:	None
Effects of Overexposure:	If taken internally, may cause intestinal upset
Emergency First Aid:	Product is for external use only. If taken internally, call doctor immediately Do not induce vomiting

Section IX Hazardous Ingredients

Hazardous components: None

All statements, information, and data provided in this MSDS are believed to be accurate and reliable, but are presented without guarantee, warranty, or responsibility of any kind, expressed or implied, on our part. Users should make their own investigations to determine the suitability of the information or products for their particular purpose. Nothing contained herein is intended as permission, inducement or recommendation to violate any laws or to practice any invention covered by existing patents.

Appendix F-7

Chemical Treatment Data

(Midwest Custom Chemical, Inc.)

MIDWEST CUSTOM CHEMICALS INC.

MIDWEST CUSTOM CHEMICAL, INC.

CUSTOM BLENDED INDUSTRIAL CHEMICALS

5700 PROSPECT DR. • P.O. BOX 727 • NEWBURGH, IN 47629 • (812) 858-3147 • FAX: (812) 858-3155

WEB-3

WASTE WATER TREATMENT
SOLUBLE OIL TREATMENT

PRODUCT BULLETIN

DESCRIPTION

WEB-3 is a blend of cationic surfactants in water. WEB-3 is used as a demulsifier for waste water and soluble oils.

TYPICAL PHYSICAL PROPERTIES

Form:	Clear liquid
Specific Gravity:	Approximately 1.1
Flashpoint:	Not Applicable
Solubility:	Water Soluble

APPLICATION

WEB-3 can be injected directly from the drum. Optimum dosage varies with temperature and extent of mixing this should be determined with testing. After initial testing, a cost effective operation will be implimented.

HANDLING AND STORAGE

Caution: This product is a corrosive liquid. Safe when used according to directions. This product is a stable material and may be stored for several months. Do not take internally. Keep away from eyes. Normal precautions in handling organic chemicals should be observed. For further information and instructions, see MSDS.

WEB-40A

ANIONIC POLYMER

PRODUCT BULLETIN

DESCRIPTION

WEB-40A is a blend of anionic polymers in water. WEB-40A is used as a flocculant and clarifier in effluent water treatment.

TYPICAL PHYSICAL PROPERTIES

Form:	Clear liquid
Specific Gravity:	Approximately 1.1
Flashpoint:	Not Applicable
Solubility:	Water Soluble

APPLICATION

WEB-40A can be injected directly from the drum. Optimum dosage, temperature, and extent of mixing should be determined for a cost effective operation.

HANDLING AND STORAGE

Caution: Safe when used according to directions. This product is a stable material and may be stored for several months. Do not take internally. Keep away from eyes. Normal precautions in handling organic chemicals should be observed. or further information and instructions see MSDS.

MATERIAL SAFETY DATA SHEET

MIDWEST CUSTOM CHEMICALS, INC.
P.O. BOX 119
EVANSVILLE, IN. 47701

REVISION DATE: March 3, 1993
EMERGENCY PHONE: 812-423-1859
CHEMTREC EMER. NO.: 800-424-9300

GENERAL

TRADE NAME: WEB-3
OTHER NAME: Clarifier/Emulsion Breaker
HAZARDOUS CLASS: Corrosive Liquid, NOS
UN/NA ID NO.: UN1760
CAS NO.: Mixture
CHEMICAL DESCRIPTION: Complex blend of surface active agents.

HAZARDOUS INGREDIENTS

CAS NUMBER	MATERIAL	EXPOSURE LIMITS	
* 7647-01-0	Muriatic Acid	OSHA PEL:	5 ppm

NFPA HAZARD RATING: H= 2 F= 0 R= 0
*Denotes an ingredient listed in SARA Title III, Section 313.
Specific chemical identities of some unlisted ingredients are being withheld for confidential business purposes.

PHYSICAL DATA

SPECIFIC GRAVITY: (H_2O=1) 1.165
VOLATILITY: Non Volatile
SOLUBILITY: Water Soluble
DRY POINT: Not Applicable
HAZARDOUS POLYMERIZATION: Will not occur.
APPEARANCE AND ODOR: Clear viscous material.
DENSITY: 9.72 lbs./gal.
VAPOR PRESSURE: Not Established
STABILITY: Stable
BOILING POINT: 220° F

FIRE AND EXPLOSION HAZARD DATA

FLASH POINT: Not Applicable
FLAMMABLE LIMITS: Not Applicable
EXTINGUISHING MEDIA: Dry chemical-water-fog-CO_2-foam-waterspray.
FIRE FIGHTING PROCEDURES: Do not enter fire area without proper protection. Decomposition products possible. Fight fire from safe distance/protected location. Heat may build pressure/rupture closed containers. Do not use solid water stream/may spread fire. Use water spray/fog for cooling. Avoid frothing/steam explosion.

UNUSUAL FIRE AND EXPLOSION HAZARDS:

When heated product may release vapors. Vapors may be heavier than air. Fine sprays/mists are corrosive.

HEALTH HAZARD

EFFECTS OF OVEREXPOSURE:

INHALATION:
Vapors or mists from this material can irritate the nose, throat and lungs.

INHALATION LC50: Not established.

SKIN CONTACT:
This material is likely to be a skin irritant.

DERMAL LD50: Not established.

INGESTION:
This material can irritate the mouth, throat and stomach and can cause nausca.

ORAL LD50: Not established.

EYE CONTACT:
Eye irritation will result from contact with liquid mist or spray.

CARCINOGENIC POTENTIAL:
Not listed in any of OSHA Standard, Section 1910.1200 sources as carcinogenic.

EMERGENCY AND FIRST AID PROCEDURES:

INHALATION:
Remove to fresh air. Call a physician.

EYE CONTACT:
Flush with water for 15 minutes. Call a physician.

SKIN CONTACT:
Wash thoroughly with soap and rinse with water. Call a physician.

INGESTION:
Do not induce vomiting. Give water. Call a physician.

EMERGENCY MEDICAL TREATMENT PROCEDURE:
Do not give anything by mouth to an unconscious person. Do not induce vomiting.

REACTIVITY DATA

STABILITY:
Stable under normal conditions of storage and use.

INCOMPATIBILITY:
Strong oxidizing agents and alkalies. Keep away from heat, sparks and open flame.

HAZARDOUS DECOMPOSITION PRODUCTS:
When heated to decomposition, produces CO_2 and CO asphyxiants.

HAZARDOUS POLYMERIZATION:
Will not occur.

SPILL AND LEAK PROCEDURES

IF MATERIAL IS SPILLED/RELEASED: Corrosive Liquid
Evacuate/limit access. Equip responders with proper protection. Kill all ignition sources. Stop release and prevent flow to sewers/public water. Impound/recover large land spill. Soak up small spill with inert solids. Use suitable disposal containers. Report per regulatory requirements.

DISPOSAL METHODS:
Contaminated product/soil/water may be RCRA/OSHA hazardous waste due to corrosivity. Place chemical residues and contaminated absorbent materials in a suitable waste container and take to an approved disposal site. Landfill solids at permitted sites. Use registered transporters to dispose in accordance with local state and federal regulations.

SPECIAL PROTECTION INFORMATION

RESPIRATORY:
When concentrations exceed the exposure limits specified, use of a NIOSH approved air respirator is recommended. When the protection factor of the respirator may be exceeded, use of a self-contained breathing unit may be necessary.

EYE:
Eye protection should be worn whenever there is a likelihood of misting splashing/spraying liquid. Suitable eye wash water should be available. Contact lenses should not be worn.

SKIN:
Avoid prolonged and/or repeated skin contact. If conditions or frequency of use make significant contact likely, wear impervious protective clothing such as gloves, boots and facial protection.

ENGINEERING CONTROLS:
Use adequate ventilation.

OTHER HYGIENIC AND WORK PRACTICES:
Use good personal hygiene practices. Wash hands before eating, drinking, smoking or use of toilet facilities. Immediately remove soiled clothing and wash it thoroughly before reuse. Clean or discard contaminated leather goods.

HANDLING, STORAGE AND DECONTAMINATION PROCEDURES:
Handle empty containers with care/residue is corrosive. Keep containers closed when not in use. Store away from heat, sparks, open flames, and strong oxidizing agents. Keep out of reach of children.

Isolate, vent, drain, wash and purge systems or equipment before maintenance or repair. Remove all ignition sources. Use adequate personal protective equipment. Observe precautions pertaining to confined space entry.

GENERAL COMMENTS:
Some of the information presented and conclusions drawn herein are from sources other than direct test data on the product itself.

DISCLAIMER OF LIABILITY

The information in this MSDS was obtained from sources which we believe are reliable. However, the information is provided without any warranty, express or implied regarding its correctness. The conditions or methods of handling, storage, use and disposal of the product are beyond our control and knowledge. For this and other reasons, we do not assume responsibility and expressly disclaim liability for loss, damage or expense arising out of or in any way connected with the handling, storage, use or disposal of the product. This MSDS was prepared and is to be used for this product. If the product is used as a component in another product, this information may not be applicable.

MATERIAL SAFETY DATA SHEET

MIDWEST CUSTOM CHEMICALS, INC.
P.O. BOX 727
NEWBURGH, IN 47629

REVISION DATE: March 1, 1993
EMERGENCY PHONE: 812-858-3147
CHEMTREC EMER. NO.: 800-424-9300

GENERAL

TRADE NAME: WEB-40A
OTHER NAME: Flocculant
HAZARDOUS CLASS: Not Applicable
UN/NA ID NO.: Not Applicable
CAS NO.: Mixture
CHEMICAL DESCRIPTION: Polymer blend.

HAZARDOUS INGREDIENTS

CAS NUMBER	MATERIAL	APPROX. %	EXPOSURE LIMITS

NOT APPLICABLE

NFPA HAZARD RATING: H= 1 F= 0 R= 0
*Denotes an ingredient listed in SARA Title III, Section 313.
Specific chemical identities of some unlisted ingredients are being withheld for confidential business purposes.

PHYSICAL DATA

SPECIFIC GRAVITY: Approx. 1.02
VOLATILITY: Non Volatile
SOLUBILITY: Water Soluble
DRY POINT: Not Applicable
HAZARDOUS POLYMERIZATION: Will not occur.
APPEARANCE AND ODOR: Clear viscous liquid.
DENSITY: 8.506 lbs./gal.
VAPOR PRESSURE: Not Applicable
STABILITY: Stable
BOILING POINT: 190° F

FIRE AND EXPLOSION HAZARD DATA

FLASH POINT: Not Applicable
FLAMMABLE LIMITS: Not Established
EXTINGUISHING MEDIA: Dry chemical-water-fog-CO_2-foam-waterspray.
FIRE FIGHTING PROCEDURES: Do not enter fire area without proper protection. Decomposition products possible. Fight fire from safe distance/protected location. Heat may build pressure/rupture closed containers. Do not use solid water stream/may spread fire. Use water spray/fog for cooling. Avoid frothing/steam explosion.

UNUSUAL FIRE AND EXPLOSION HAZARDS:

Containers exposed in fire should be cooled with water to prevent vapor pressure buildup leading to rupture. In the event of combustion CO, CO_2 may be formed. Do not breathe smoke or fumes. Wear suitable protective equipment.

HEALTH HAZARD

EFFECTS OF OVEREXPOSURE:

INHALATION:
Not Applicable.

INHALATION LC50: Not established.

SKIN CONTACT:
Contact with skin may cause irritation.

DERMAL LD50: Not established.

INGESTION:
Ingestion may cause irritation.

ORAL LD50: Not established.

EYE CONTACT:
Contact with eyes may cause eye irritation.

CARCINOGENIC POTENTIAL:
Not listed in any of OSHA Standard, Section 1910.1200 sources as carcinogenic.

EMERGENCY AND FIRST AID PROCEDURES:

INHALATION:
Not Applicable.

EYE CONTACT:
Flush with water for 15 minutes. Call a physician.

SKIN CONTACT:
Wash thoroughly with soap and rinse with water. Call a physician.

INGESTION:
Do not induce vomiting. Give water. Call a physician.

EMERGENCY MEDICAL TREATMENT PROCEDURE:
Do not give anything by mouth to an unconscious person. Do not induce vomiting.

REACTIVITY DATA

STABILITY:
Stable under normal conditions of storage and use.

INCOMPATIBILITY:
Strong oxidizing agents. Keep away from heat, sparks and open fire.

HAZARDOUS DECOMPOSITION PRODUCTS:
When heated to decomposition, produces CO_2 and CO asphyxiants.

HAZARDOUS POLYMERIZATION:
Will not occur.

SPILL AND LEAK PROCEDURES

IF MATERIAL IS SPILLED/RELEASED:
Evacuate area/limit access.

Small spill: Absorb on paper, cloth, or other material.

Large spill: Dike to prevent entering any sewer or waterway. Transfer liquid to a holding container. Cover residue with dirt or suitable chemical absorbent. Use personal protective equipment if necessary.

DISPOSAL METHODS:
Place chemical residue and contaminated absorbent material into suitable waste container and take to an approved waste disposal site. Dispose of all residue in accordance with state, local, and federal regulations.

SPECIAL PROTECTION INFORMATION

RESPIRATORY: Not Applicable.

EYE: Wear goggles or face shield.

SKIN: Wear chemical resistant gloves and synthetic apron or coveralls.

ENGINEERING CONTROLS:
General ventilation should be provided to maintain ambient concentrations below recommended exposure limits.

OTHER HYGIENIC AND WORK PRACTICES:
Use good personal hygiene practices. Wash hands before eating, drinking, smoking or use of toilet facilities. Immediately remove soiled clothing and wash it thoroughly before reuse. Clean or discard contaminated leather goods.

HANDLING, STORAGE AND DECONTAMINATION PROCEDURES:
Handle empty containers with care. Keep containers closed when not in use. Store away from heat, sparks, open flames, and strong oxidizing agents. Keep out of reach of children.

Isolate, vent, drain, wash, and purge systems or equipment before maintenance or repair.

GENERAL COMMENTS:
Some of the information presented and conclusions drawn herein are from sources other than direct test data on the product itself.

DISCLAIMER OF LIABILITY

Post-it® Fax Note 7672

To Casey Watson		From Henri Meyer	
Co./Dept.		Co. MCC	
Phone #		Phone #	
Fax # 302-677-4166		Fax #	

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MSDS – WEB3, WEB 40A
Product Bulletin – WEB-3, WEB 40A
Test Procedure.

MIDWEST CUSTOM CHEMICAL, INC.
CUSTOM BLENDED INDUSTRIAL CHEMICALS
5700 PROSPECT DR. • P.O. BOX 727 • NEWBURGH, IN 47629 • (812) 858-3147 • FAX: (812) 858-3155

WASTE WATER TREATMENT TEST PROCEDURE

- In a graduated beaker glass with waste water add 250-1000 ppm WEB-3 (coagulant) to the waste water.
- Mix the WEB-3 for 5 - 10 minutes on a stirring plate (a small pin floc will occur).
- Check pH. Adjust the pH to 8 - 9 if necessary with caustic (50%) or lime.
- Add 250-500 ppm WEB-40A. Mix the chemical until a large floc develops.
- Filter water through filter paper and test for COD, BOD, etc.